LABORATORY EXPERIMENTS IN METALLURGY

ALBERT SAUVEUR
AND
H.M.BOYLSTON

Presented by the Author to
K.E.S. Hamilton and by him
for the use of Students in
Applied Science.

LABORATORY EXPERIMENTS IN METALLURGY

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To

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THIS LITTLE BOOK IS DEDICATED BY THE AUTHORS
AS A MARK OF WARM PERSONAL ESTEEM
AND IN APPRECIATION OF HIS WORK
IN INTRODUCING AND PRO-
MOTING THE STUDY

OF

Mining and Metallurgy

IN

HARVARD UNIVERSITY

PREFACE.

These short notes, describing some experiments in Metallurgy, are written primarily for the use of students at Harvard University who take the courses in General Metallurgy and in the Metallurgy of Iron and Steel. While fully aware of their many shortcomings, especially in failing to deal exhaustively with the subject, the authors hope, however, that these notes may prove suggestive, at least, to other teachers and students in Metallurgy, and even to practitioners of the art.

It is their intention in subsequent editions to describe a greater number of possible and useful laboratory experiments, and to otherwise improve this little book. Had they waited until satisfied that the subject was exhaustively and faultlessly treated, the book would never have been written.

The authors invite, and will receive gratefully, the criticisms and suggestions of their co-workers and of other interested persons.

ALBERT SAUVEUR.
H. M. BOYLSTON.

HARVARD UNIVERSITY,
October, 1908.

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The experiments described in Part I. can be arranged readily in six groups as indicated below, and each group can be performed easily in a period of three hours.

Group.	Experiments.
1.	1.
2.	2.
3.	3, 4 and 5.
4.	6, 7 and 8.
5.	9, 10 and 11.
6.	12 and 13.

Each of the experiments in Part II. requires about three hours for its proper performance, with the exception of Experiments 17 and 18, which can both be performed easily in one period of three hours. These estimates are based on a class or section of twelve students and an average amount of apparatus.

PART I. GENERAL METALLURGY.

Experiment 1.

COKING AND PROXIMATE ANALYSIS OF COAL.

Weigh 10 grams of finely-powdered bituminous caking coal in an iron crucible (Fig. 1). Cover the crucible with a special iron cover and clamp it tight. Connect the brass tube passing through the cover with a bottle, which has been previously weighed, by means of rubber tubing and a double-bored stopper. The gas which will enter the bottle is allowed to escape through a glass tube bent at right angles and drawn to a small opening at the outer end.

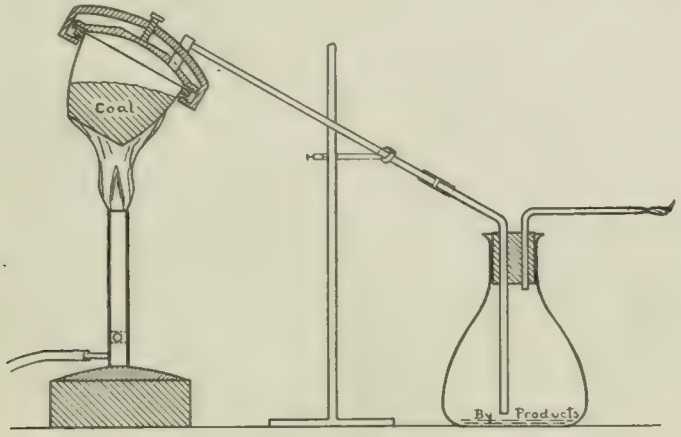


Fig. 1. — Apparatus for Coking and Proximate Analysis of Coal.

We have in this way (1) a retort in which the coal can be distilled, and (2) a bottle in which the by-products may be collected by condensation, while the permanent gases will escape at the small end of the glass tube.

Destructive distillation. — The iron crucible should now be heated by means of a Bunsen burner. At first steam will be noticed to fill the glass bottle, indicating that the moisture contained in the coal is first expelled during the process of distillation. The heat should be gradually increased until the full heat of two blast lamps is playing on the crucible. The other volatile matters contained in the coal will now be expelled, and the residue left in the crucible at the end of this operation is known as coke.

By-products. — The volatile matters expelled from the coal carry with them a large amount of tar and ammoniacal liquor known as by-products, which can be recovered by cooling the gases before they are allowed to escape. In this apparatus, by forcing the gases

to pass through the glass bottle, the necessary cooling is effected and some of the by-products will condense and fall to the bottom of the bottle. They will be found to consist of a watery ammoniacal liquor and of a dark residue of tar. At the end of the operation the bottle and its contents should be weighed and the percentage of by-products yielded by the coal calculated and recorded. The by-products should be tested for alkalinity with a small strip of red litmus paper.

Permanent gases. — The gases which escape from the bottle after deposition of the by-products are known as permanent gases. They consist chiefly of various hydrocarbons and are frequently used as illuminating gases. After the distillation has been carried on for fifteen minutes, the permanent gases may be lighted and they will be found to burn with a luminous flame. By subtracting from the weight of the coal the weight of the by-products and of the coke, the weight of the permanent gases will be obtained. This should be calculated in percentage and recorded.

End of the operation. — After the permanent gases cease to burn, continue heating for ten minutes longer, and then remove the burner and allow the crucible to cool.

Coke. — When the crucible is sufficiently cool, open it and examine its contents. It will be found to consist of a hard mass of caked and swollen coke. Remove the coke and weigh it. Figure out the percentage of coke yielded by the coal and record it.

Ash and fixed carbon. — This coke consists of ash and carbon (known as fixed carbon). To determine these separately, grind the coke very fine and burn this pulverized coke in a roasting dish placed in a furnace until all the carbon has been burned. The residue represents the ash. It should be placed on a cover glass, allowed to cool, and weighed. Figure the percentage of ash yielded by the coal. The loss in weight represents the fixed carbon, which should be recorded in percentage.

Non-caking coal. — Exactly the same experiment should be repeated with 10 grams of non-caking coal. The resulting coke will be found to be pulverulent, the particles of coal having failed to cohere when the distillation took place; or if a coke is formed, it is extremely weak and easily pulverized in the fingers.

TABLE 1. — TYPICAL ANALYSES OF VARIOUS FUELS.

TYPE OF FUEL.	PROXIMATE ANALYSIS.				CALORIFIC POWER.		SOURCE OF INFORMATION.
	Volatile Matter. Per Cent.		Fixed Carbon. Per Cent.	Ash. Per Cent.	Calories.	B. T. U.	
Non-caking Bituminous Coal.	18.2		72.6	9.2	7,750	13,961	Report of the Coal Testing Plant of the United States Geological Survey, Professional Paper No. 48, 1906.
	38.0		50.7	11.3	6,724	12,103	
	38.9		36.1	25.0	5,201	9,362	
Caking Bituminous Coal.	41.9		50.3	7.9	7,700	13,860	
	30.1		61.5	8.4	7,855	14,139	
	20.3		75.1	4.6	8,439	15,190	
	By-Products.	Permanent Gases.					
	4.2	11.2	81.6	3.0	7,709	13,877	Average of many results at Harvard University, 1906–8.
Anthracite Coal.	2.9	1.8	89.1	6.2	7,650	13,768	
	2.4	4.2	81.5	11.9	7,216	12,990	
Charcoal.	Average of 58 determinations on 3 different samples.				6,842	12,316	Harvard University, 1905–8.

Experiment 1.

LABORATORY REPORT.

FUELS — Coking and Proximate Analysis of Coal.

Description of Coal used:

Weight of Coal:

,, Coke:

,, Volatile Matters:

,, By-products:

,, Permanent Gases:

,, Ash:

,, Fixed Carbon:

	Per Cent.		Per Cent.
Coke		Ash	
		Fixed Carbon	
Volatile Matters		By-products	
		Permanent Gases	

Character of Coke:

Remarks: *Date:*

Experiment 2.

CALORIMETRY.

The Parr Calorimeter. — Fig. 2 shows the relative position of parts. The can, *A*, is filled with two liters of water. The combustion takes place within the cartridge, *D*. The resulting heat is imparted to the water. The rise in temperature is indicated by the finely graduated thermometer, *T*. *B* and *C* are pails of papier-maché, and these, with the air spaces between *B* and *C*, and between *C* and *A*, serve to insulate the calorimeter can, *A*. *F* is a bearing upon which the cartridge, *D*, turns, and *E* is a metal cylinder which prevents the water from waving while being stirred and also aids the stirring by inducing the water to move in a current as indicated by the arrows.

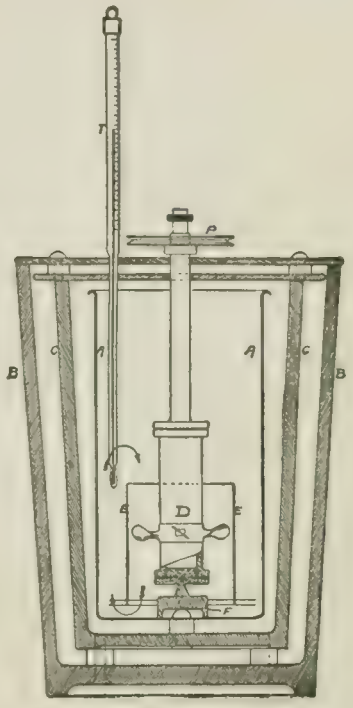


Fig. 2. — The Parr Calorimeter.

Calorific power of charcoal. — Grind a small amount of charcoal in a mortar so that it will pass through a sieve of 100 meshes to the linear inch. Weigh accurately 0.5 gram of this crushed charcoal, add ½ gram of "accelerator," and mix thoroughly on white glazed paper.

Next take one full measure of the "chemical," pour half of this into the cartridge; pour the mixture of charcoal and "accelerator" into the cartridge, brushing off the last adhering particles of the mixture with a small camel's hair brush; on top of this pour in the remaining half measure of "chemical," and stir the entire contents of the cartridge carefully with a small glass rod. Close the cartridge with the top and stem, to which is properly attached a loop of fine wire about one inch long. Screw the top firmly into place and tap the cartridge gently so that the charge will settle at the bottom.

Fasten on the spring clips with vanes.

Place the can, *A*, containing the cylinder, *E*, inside the pail, *C*.

Fill the can with exactly 2 liters of water, preferably at a temperature some 3° F. above that of the room.[1]

[1] If the water is much warmer than the air in the room, loss of heat by radiation is liable to occur; while if it is cooler than the air, dew will be deposited upon the can, *A*, and thus increase its weight.

Introduce the cartridge into the can.

Adjust the cover and insert the thermometer so that the lower end of the bulb will be about midway towards the bottom of the can.

Make the necessary connections for the ignition current.

Place the pulley on the stem, connect it with the motor, and start the latter.

After about three minutes take and record the first reading of the thermometer.

Ignition should now be produced by closing the electric circuit and without stopping the revolving of the cartridge.

Observe carefully and record the maximum rise of the mercury, which should be attained in four or five minutes.

Subtract the correction factor for the heat due to the combustion of the wire and the reaction of the " accelerator."

Multiply the remainder by 3115.[1]

The product indicates the calorific power of the fuel tested in British Thermal Units.

To convert the British Thermal Units into calories (Centigrade units), divide by 1.8.

Repeat this determination.

Calorific power of coal. — Ascertain the calorific power of a previously dried sample[2] of anthracite coal exactly in the same manner.

Repeat this determination.[3]

---

[1] The formula for computing the calorific power of a substance when burned in a water calorimeter is

$$\text{Calorific power} = \frac{T\,(W + w)}{F}$$

Where T = the observed rise of temperature (corrected).
W = weight of water in the calorimeter.
w = water equivalent of the vessel = weight of the vessel × its specific heat.
F = weight of fuel taken.

In our case, W, w, and F are constants, and the formula becomes

$$\text{Calorific power} = \frac{T\,(2000 + 134)}{0.5} = 4268\ T.$$

But it has been ascertained by careful experiment with the Parr calorimeter that only 73 per cent of the heat produced comes from the combustion of the fuel, so

$$\text{Calorific power} = 0.73 \times 4268\ T = 3115\ T.$$

Thus, if T is measured in degrees Fahrenheit, the observed rise in temperature multiplied by the factor 3115 is the calorific power of the fuel tested in B.T.U. per pound. If T is measured in degrees Centigrade, the answer is obtained in calories per gram.

[2] Samples of coal should be previously dried for one hour at 105–110° C.

[3] For the calorific power of various fuels see Table 1, page 2.

Experiment 2.

LABORATORY REPORT.

CALORIMETRY — Parr Calorimeter.

	1.	2.	3.
Description of Fuel:			
Weight of Fuel:			
Reading of thermometer before ignition:			
„ „ after ignition:			
Rise of temperature:			
Correction:			
Net rise of temperature:			

Calorific power:

		British Thermal Units.		Calories.
1.	× 3115 =		÷ 1.8 =	
2.	× 3115 =		÷ 1.8 =	
3.	× 3115 =		÷ 1.8 =	

Remarks: *Date:*

Experiments 3, 4, and 5. PYROMETRY.

The student should familiarize himself thoroughly with the principles and construction of the pyrometers used in these experiments. For additional description of these instruments,[1] he is referred to pages 272 and 279 of "Fuel," by Sexton, and to page 30 of "Metallurgical Laboratory Notes," by Howe.

Experiment 3.

THE SIEMENS WATER PYROMETER.

Description. — The pyrometer is shown in vertical section in Fig. 3. It consists of a cylindrical copper vessel containing a second smaller copper vessel with double walls. An air space *a* separates the two vessels, and a layer of felt the two walls of the inner one, in order to retard the exchange of temperature with the surroundings. The capacity of the inner vessel is a little more than one pint. A mercury thermometer, *b*, is fixed close to the wall of the inner vessel, its lower part being protected by a perforated brass tube, whilst the upper projects above the vessel and is divided as usual on the stem into degrees, Fahrenheit or Centigrade, as desired. At the side of the thermometer there is a small brass scale, *c*, which slides up and down, and on which the high temperatures are marked in the same degrees as those in which the mercury thermometer is divided; on a level with the zero division of the brass scale a small pointer is fixed, which traverses the scale of the thermometer.

Short cylinders, *d*, of either copper, iron, or platinum, are supplied with the pyrometer, which are so adjusted that their heat capacity at ordinary temperature is equal to one fiftieth of that of the copper vessel filled with one pint of water. As, however, the specific heat of metals increases with the temperature, allowance is made on the brass sliding scales, which are divided according to the metal used for the pyrometer cylinders, *d*. It will, therefore, be understood that a different sliding scale is required for the particular kind of metal of which a cylinder is composed. In order to obtain accurate measurements, each sliding scale must be used only in conjunction with its own thermometer, and in case the latter breaks, a new scale must be made and graduated for the new thermometer.

For ordinary furnace work either copper or wrought-iron cylinders may be used. Iron cylinders possess a higher melting point and have less tendency to scale than those of copper, but the latter are much less affected by the corrosive action of the furnace gases; platinum is, of course, not subject to any of these disadvantages.

The weight to which the different metal cylinders are adjusted is as follows:

Copper	137 grams
Wrought-iron	112 „
Platinum	402.6 „

In course of time the iron and the copper cylinders lose weight by scaling; the tables subjoined give for the diminished weights the percentage by which the readings on the brass scale are to be increased.

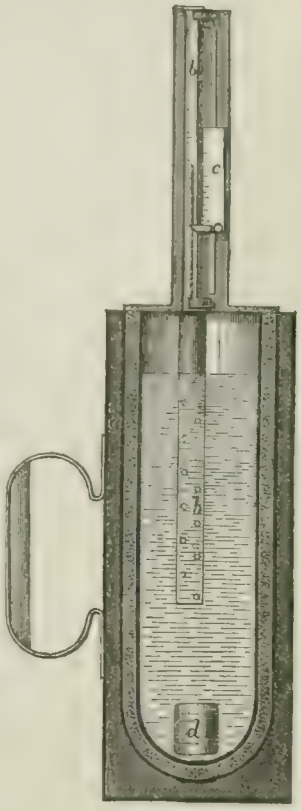


Fig. 3.
The Siemens Water Pyrometer.

[1] See also "High Temperature Measurements," by H. Le Chatelier and O. Boudouard, translated by G. K. Burgess, and "Optical Pyrometry," by C. W. Waidner and G. K. Burgess, Bulletin of the United States Bureau of Standards. I, No. 2, 1904.

TABLE 2. — CORRECTIONS FOR THE DECREASE IN WEIGHT OF THE IRON CYLINDERS, APPLICABLE BOTH TO FAHRENHEIT AND CENTIGRADE THERMOMETER SCALES.

Weight of Iron Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.	Weight of Iron Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.	Weight of Iron Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.
112	0.000	104	7.7	96	16.7
111	0.9	103	8.7	95	17.9
110	1.8	102	9.8	94	19.1
109	2.8	101	10.9	93	20.4
108	3.7	100	12.0	92	21.7
107	4.7	99	13.1	91	23.1
106	5.7	98	14.3	90	24.4
105	6.7	97	15.5	89	25.8

TABLE 3. — CORRECTIONS FOR THE DECREASE IN WEIGHT OF THE COPPER CYLINDERS, APPLICABLE BOTH TO FAHRENHEIT AND CENTIGRADE THERMOMETER SCALES.

Weight of Copper Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.	Weight of Copper Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.	Weight of Copper Cylinder in Grams.	Percentage Increase. For the Indications of the Sliding Scale.
137	0.000	131	4.6	125	9.6
136	0.7	130	5.4	124	10.5
135	1.5	129	6.2	123	11.4
134	2.2	128	7.0	122	12.3
133	3.0	127	7.8	121	13.2
132	3.8	126	8.7	120	14.2

Principle. — The instrument is really a water calorimeter and its working depends upon the fact that the heat gained by the water in the instrument and by the vessel containing that water is equal to the heat lost by the metal cylinder after dropping it into the water. The temperature of the metal cylinder, *i. e.*, the temperature of the furnace in which the cylinder has been heated, can then be calculated from the resulting equation.

Let W = weight of water.
w' = weight of the copper vessel.
s' = specific heat of this vessel.
T = temperature of the water after immersion of cylinder.
t = temperature of the water before immersion of cylinder.
w'' = weight of the cylinder.
s'' = specific heat of the cylinder.
X = temperature of the cylinder before immersion and therefore of the furnace being tested.

The amount of heat gained by the water and by the vessel containing it $= (W + w's') \times (T - t)$.
The amount of heat lost by the cylinder $= w''s''(X - T)$.
Then by assumption $w''s''(X - T) = (W + w's') \times (T - t)$.

Solving for X we have $X = T + \dfrac{(W + w's') \times (T - t)}{w''s''}$.

The instrument used in this laboratory, however, is so constructed that the weight of the cylinder multiplied by its specific heat ($w''s''$) bears a definite relation to the weight of the water plus the product of the weight of the vessel by its specific heat ($W + w's'$), so that the brass scale can be and has been calibrated to read directly in degrees the temperature of the cylinder and therefore of the furnace whose temperature is desired.

The Siemens Water Pyrometer. — Method of mixtures. — Procedure. — Fill the calorimeter with 473 cc. (1 pint) of water and adjust the zero of the brass scale to the level of the mercury in the thermometer.

Place the small cylinder (of iron or other metal) on a scorifier in a furnace which has previously been heated to a red heat. Allow the cylinder to remain in the furnace fifteen minutes so that it may acquire the temperature of the furnace.

By means of a pair of tongs whose ends have been preheated (so as to reduce the possible loss of heat by conductivity) remove quickly from the furnace the cylinder and drop it into the calorimter without splashing.

Cover the top with a piece of cardboard and note carefully the highest temperature indicated by the thermometer. The corresponding division on the adjoining brass scale will indicate the actual temperature of the cylinder when removed from the furnace and therefore the temperature of the furnace itself at that time.

The temperature ascertained by the use of this pyrometer should be checked simultaneously by means of a Le Chatelier thermo-couple, whose protected hot junction should be already in place near the scorifier containing the metal cylinder.

This experiment should be performed at least three times, each student taking his turn at the reading of the thermometer, handling of the cylinder, etc.

All readings should be entered on the report, both in Fahrenheit and Centigrade degrees.

Experiment 4.

THE MESURÉ AND NOUEL OPTICAL PYROMETER.

Description. — The instrument is shown in Fig. 4 and consists essentially of the following parts. *A* and *P* are two Nicol prisms, called respectively the analyzer and the polarizer. Between these is a quartz plate, *Q*, which is cut perpendicularly to its principal mineralogical axis. *CC* is a circle graduated in degrees attached to the analyzer and moves before a fixed index, *I*. A lens, *L*, acts as an eyepiece and views the opposite opening, *O*, furnished with a parallel faced plate glass. A collimator, with or without a movable objective (for focusing the instrument) is generally used, but is not shown in the illustration.

Principle. — It is well known that a plate of quartz cut perpendicularly to its principal axis will rotate the plane of a ray of polarized light, the angle of rotation depending upon the thickness of the quartz and upon the wave-length of the light, which is a function of the temperature of the heated body which emits the light.

If such a plate of quartz is placed between two Nicol prisms and a luminous body viewed through this combination, a certain position of the analyzer will correspond to a green hue, while if the analyzer be rotated to the left a sudden change to a bright red hue is noticed. The transition point red-green is called the sensitive hue of the instrument and the angle at which the circle *CC* stands when this sensitive hue (often described as a grayish yellow) is obtained, depends upon the thickness of the quartz plate which is fixed for the instrument, and upon the wave-length of the light emitted from the luminous body, which is a function of its temperature. Thus the higher the temperature of the luminous body, the greater the angle of rotation of the analyzer which is attached to the circle *CC*. The instrument used in this laboratory has been carefully calibrated with a Le Chatelier thermo-couple and the temperatures corresponding to the various angles indicated on the circle *CC* are given in Table 4.

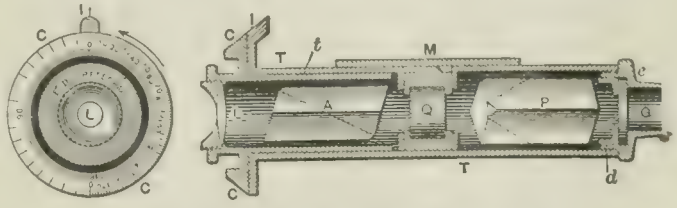


Fig. 4. — Mesuré and Nouel Optical Pyrometer (after Le Chatelier and Boudouard).

Mesuré and Nouel Optical Pyrometer. — Procedure. — Heat a muffle furnace to a bright red heat and observe the interior of the furnace by means of the Mesuré and Nouel pyrometer, and preferably through a small opening in the furnace door. The pyrometer should be focused (by moving the objective) on the end of the porcelain tube containing the hot junction of a Le Chatelier thermo-couple.

Place the index of the pyrometer at the zero point and move slowly the graduated disk of the instrument to the left until the green tint has disappeared and stop before the reddish tint appears. The passage of the greenish to the reddish coloration is quite abrupt and after a few trials there should not be much difficulty in securing the desired position. The color corresponding to this position is generally defined as grayish yellow. The best test is to see that it is free both from greenish and reddish tints, rotating the analyzer tentatively back and forth until the proper tint is secured.

The number of divisions on the graduated circle should now be noted, and by referring to Table 4 the corresponding temperature of the furnace will be found.

This experiment should be conducted by each student and the temperature recorded, both in degrees Centigrade and Fahrenheit.

The temperature as ascertained by the use of this pyrometer should be checked simultaneously by means of the Le Chatelier thermo-couple whose protected hot junction is already in place in the furnace.

Each student should draw his own conclusion as to the relative merits of the three pyrometers.

TABLE 4.[1]

TEMPERATURE TABLE FOR USE WITH THE MESURÉ AND NOUEL PYROMETER.

MESURÉ AND NOUEL.	LE CHATELIER.	
Reading in Angular Degrees.	Deg. F.	Deg. C.
32	1112	600
33	1202	650
34	1292	700
35	1337	725
36	1382	750
37	1427	775
38	1472	800
39	1517	825
40	1562	850
41	1592	867
42	1622	883
43	1652	900
44	1697	925
45	1742	950
46	1787	975
47	1832	1000
48	1877	1025
49	1922	1050
50	1952	1067
51	1982	1083
52	2012	1100

[1] In calibration of the Mesuré and Nouel pyrometer, readings were taken only at intervals of 50° C., beginning with 600° C. and ending with 1100° C. All other values in the above table were found by interpolation.

Experiments 3 and 4.

LABORATORY REPORT.

PYROMETRY.

Temperature of Furnace ascertained by the simultaneous use of two Pyrometers.

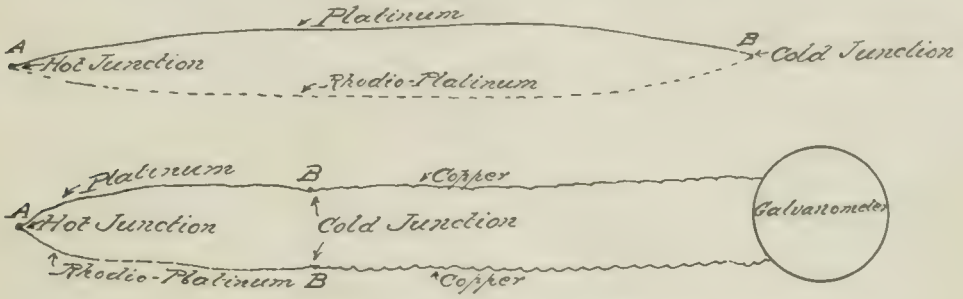
	SIEMENS.					LE CHATELIER.				
	Cylinder No.	Temp. Deg. F.	Correction Deg. F.	Corrected Temperature of Furnace.		Temp. Deg.	Correction for Cold Junction.	Corrected Temperature of Furnace.		
				Deg. F.	Deg. C.			Deg. F.	Deg. C.	
1st Reading										
2d Reading										
3d Reading										

	MESURÉ AND NOUEL.		
	Angle of Rotation.	Temperature of Furnace.	
		Deg. F.	Deg. C.
1st Reading			
2d Reading			
3d Reading			

Experiment 5.

THE LE CHATELIER THERMO-ELECTRIC PYROMETER.

Principle. — If the ends of two wires of different metals are connected and one of the junctions is heated, while the other is kept cool, a slight electric current will flow through the circuit because of the difference in temperature between the two junctions. Fig. 5 shows such a circuit with one wire of platinum and the other of platinum alloyed with 10% rhodium. The same principle holds if, instead of joining the two ends constituting the cold junction, they are connected indirectly through copper leads of suitable size with a galvanometer (see Fig. 6). If the cold junction is now maintained at 0° C., the temperature of the hot junction is in definite relation to the difference in potential between the two ends constituting the cold junction. This difference in potential or voltage is measured by means of a milli voltmeter. With wires of platinum and rhodio-platinum, thermo-couples have been constructed which



Figs. 5 and 6. — Le Chatelier Thermo-electric Pyrometer (after Howe).

by means of a properly calibrated millivoltmeter (galvanometer) will indicate the temperature directly in degrees Centigrade or Fahrenheit of the hot junction of the thermo-couple and therefore of any body in which the hot junction is imbedded. Of course, for accurate readings the cold junction must be at 0° C., but for ordinary work it is sufficient to add a correction[1] for the temperature of the cold junction to the registered temperature. This may be accomplished by inserting the cold junction in a bottle of water in which is suspended a thermometer, the temperature of the water and therefore of the cold junction being added to the galvanometer reading. The Le Chatelier thermo-electric pyrometer has already been used in Experiments 3 and 4 to check the readings of the Siemens water pyrometer and the Mesuré and Nouel optical pyrometer, but to further illustrate its use, the heating and cooling curves of a furnace will be ascertained and plotted.

Heating and cooling curves of furnaces. — Place the couple of the Le Chatelier pyrometer in a furnace and light the furnace. Watch carefully the rise of temperature as indicated by the galvanometer. Take note of the time required for each successive rise of temperature corresponding to one division of the galvanometer until a temperature of 1000° C. (or 1800° F.) has been reached.

This can best be done by a squad of three students as follows: One student will watch carefully the galvanometer and call the temperature whenever the needle passes one division of the instrument, another student will call the corresponding time in minutes and seconds, while the third student will record both time and temperature on a printed form supplied for that purpose (pages 15 and 16).

[1] For a discussion of "Cold-junction Temperature Corrections" in accurate work, see an article on this subject by C. Offerhaus and E. H Fischer, in the "Electrochemical and Metallurgical Industry." Vol. vi, 1908, page 362 *et seq.*

After the furnace has thus been heated to 1000° C., shut off the gas and watch the cooling of the furnace exactly as in heating, recording the time at which the needle of the galvanometer passes each division until the furnace has cooled down to 500° C. (or 900° F.).

By subtracting these successive readings, the length of time actually required for the rise or fall of the temperature through each division will be obtained.

These time intervals should now be recorded on a sheet of plotting paper as abscissæ (plotting each interval from zero), while the corresponding temperatures are plotted as ordinates.

Draw a smooth curve through all the points obtained in heating, and another curve through the points obtained in cooling. The heating and cooling curves of the furnace will thus have been constructed and will indicate the speed, uniformity, etc., with which the furnace can be heated or cooled under the prevailing conditions.

Data for Heating and Cooling Curves of Furnace No. ....

	HEATING.			COOLING.			
	Temperature Deg. Fahr.	Time.	Difference.	Temperature Deg. Fahr	Time.	Difference.	
.....	900	.....	.....	1800	.....	.....	.....
.....	925	.....	.....	1775	.....	.....	.....
.....	950	.....	.....	1750	.....	.....	.....
.....	975	.....	.....	1725	.....	.....	.....
.....	1000	.....	.....	1700	.....	.....	.....
.....	1025	.....	.....	1675	.....	.....	.....
.....	1050	.....	.....	1650	.....	.....	.....
.....	1075	.....	.....	1625	.....	.....	.....
.....	1100	.....	.....	1600	.....	.....	.....
.....	1125	.....	.....	1575	.....	.....	.....
.....	1150	.....	.....	1550	.....	.....	.....
.....	1175	.....	.....	1525	.....	.....	.....
.....	1200	.....	.....	1500	.....	.....	.....
.....	1225	.....	.....	1475	.....	.....	.....
.....	1250	.....	.....	1450	.....	.....	.....
.....	1275	.....	.....	1425	.....	.....	.....
.....	1300	.....	.....	1400	.....	.....	.....
.....	1325	.....	.....	1375	.....	.....	.....
.....	1350	.....	.....	1350	.....	.....	.....
.....	1375	.....	.....	1325	.....	.....	.....
.....	1400	.....	.....	1300	.....	.....	.....
.....	1425	.....	.....	1275	.....	.....	.....
.....	1450	.....	.....	1250	.....	.....	.....
.....	1475	.....	.....	1225	.....	.....	.....
.....	1500	.....	.....	1200	.....	.....	.....
.....	1525	.....	.....	1175	.....	.....	.....
.....	1550	.....	.....	1150	.....	.....	.....
.....	1575	.....	.....	1125	.....	.....	.....
.....	1600	.....	.....	1100	.....	.....	.....
.....	1625	.....	.....	1075	.....	.....	.....
.....	1650	.....	.....	1050	.....	.....	.....
.....	1675	.....	.....	1025	.....	.....	.....
.....	1700	.....	.....	1000	.....	.....	.....
.....	1725	.....	.....	975	.....	.....	.....
.....	1750	.....	.....	950	.....	.....	.....
.....	1775	.....	.....	925	.....	.....	.....
.....	1800	.....	.....	900	.....	.....	.....

Data for Heating and Cooling Curves of Furnace No. _____

HEATING.		
Temperature Deg. C.	Time.	Difference.
500		
510		
520		
530		
540		
550		
560		
570		
580		
590		
600		
610		
620		
630		
640		
650		
660		
670		
680		
690		
700		
710		
720		
730		
740		
750		
760		
770		
780		
790		
800		
810		
820		
830		
840		
850		

HEATING.		
Temperature Deg. C.	Time.	Difference.
860		
870		
880		
890		
900		
910		
920		
930		
940		
950		
960		
970		
980		
990		
1000		

COOLING.		
Temperature Deg. C.	Time.	Difference.
1000		
900		
980		
970		
960		
950		
940		
930		
920		
910		
900		
890		
880		
870		
860		

COOLING.		
Temperature. Deg. C.	Time.	Difference.
850		
840		
830		
820		
810		
800		
790		
780		
770		
760		
750		
740		
730		
720		
710		
700		
690		
680		
670		
660		
650		
640		
630		
620		
610		
600		
590		
580		
570		
500		
550		
540		
530		
520		
510		
500		

Table 5.

Comparison of Thermometric Scales, for every 10° C. and every 25° F.

C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.
—17.8	0.0	260	500	550	1022	774	1425	1000	1832	1200	2354	1580	2875
0.0	32	270	518	552	1025	779	1434			1202	2372	1585	2876
10.0	50	274	525	560	1040	780	1436	1010	185[illegible]			1590	2884
20.0	68	280	536	566	1050	788	1450	1020	1868	1302	2375	1593	2900
23.0	75	288	550	570	1058	790	1454	1024	1875	1310	2390	1600	2912
30.0	86	290	554	580	1075	794	1461	1038	1886	1316	2400		
37.8	100	300	572	580	1076	800	1472	1038	190[illegible]	1320	2408	1625	2957
40.0	104			590	1094			1040	1904	1329	2425	1650	3002
50.0	122	302	575	593	1100	802	1475	1050	1922	1330	2426	1675	3047
51.7	125	310	590	600	1112	808	1486	1052	1925	1340	2444	1700	3092
60.0	140	316	600			810	1490	1060	1940	1343	2450	1750	3182
65.6	150	320	608	607	1125	816	1500	1066	1950	1350	2462	1800	3272
70.0	158	330	625	610	1130	820	1508	1070	1958	1357	2475	1850	3362
79.4	175	330	626	620	1148	830	1525	1080	1975	1360	2480	1900	3452
80.0	176	340	644	621	1150	839	1526	1080	1976	1370	2498	1950	3542
90.0	194	343	650	630	1166	840	1544	1090	1994	1371	2500	2000	3632
93.3	200	350	662	635	1175	843	1550	1093	2000	1380	2516	2050	3722
100	212	357	675	640	1184	850	1562	1100	2012	1385	2525	2100	3812
		360	680	640	1200	851	1564			1390	2534		
107	225	370	698	650	1202	857	1575	1107	2025	1399	2550		
110	230	371	700	657	1215	860	1580	1110	2030	1400	2552		
120	248	380	716	660	1220	860	1581	1120	2048				
121	250	385	725	663	1225	870	1598	1121	2050	1410	2570		
130	266	390	734	664	1227	871	1600	1130	2066	1413	2575		
135	275	399	750	670	1238	880	1616	1135	2075	1420	2588		
140	284	400	752	677	1250	882	1620	1140	2084	1427	2600		
149	300			678	1252	885	1625	1149	2100	1430	2606		
150	302	410	770	680	1256	890	1634	1150	2102	1440	2624		
160	320	413	775	690	1274	897	1647	1160	2120	1441	2625		
163	325	420	788	691	1275	899	1650	1163	2125	1450	2642		
170	338	427	800	693	1280	900	1652	1170	2138	1455	2650		
177	350	430	800	700	1292			1177	2150	1460	2660		
180	356	440	824			910	1670	1180	2156	1469	2675		
190	374	441	825	705	1300	913	1675	1190	2174	1470	2678		
191	375	450	842	707	1304	920	1688	1191	2175	1480	2696		
200	392	455	850	709	1308	927	1700	1200	2192	1482	2700		
		460	860	710	1310	930	1706			1490	2714		
204	400	469	875	714	1317	940	1724	1205	2200	1496	2725		
210	410	470	878	710	1325	941	1725	1210	2210	1500	2732		
218	425	480	896	720	1328	950	1742	1210	2225				
220	428	482	900	722	1332	952	1740	1220	2228	1510	2750		
230	446	490	914	726	1338	955	1750	1230	2240	1520	2768		
232	450	496	925	730	1340	960	1760	1232	2250	1524	2775		
240	464	500	932	732	1350	969	1775	1240	2264	1530	2786		
246	475			736	1357	970	1778	1246	2275	1538	2800		
250	482	510	950	737	1359	973	1783	1250	2282	1540	2804		
		520	968	740	1364	980	1796	1260	2300	1550	2822		
		524	975	746	1375	982	1800	1270	2318	1552	2825		
		530	986	750	1382	984	1803	1274	2325	1560	2840		
		538	1000	750	1393	990	1814	1280	2336	1566	2852		
		540	1004	760	1400	996	1825	1288	2350	1570	2858		
				770	1418								

C.	F.
1° =	1.8°
2° =	3.6°
3° =	5.4°
4° =	7.2°
5° =	9.0°
6° =	10.8°
7° =	12.6°
8° =	14.4°
9° =	16.2°

Formulæ for converting from one scale into the other:

$$F = \frac{9C}{5} + 32;$$

$$C = \frac{5\,(F - 32)}{9}$$

F = degrees Fahrenheit.

C = degrees Centigrade.

With the exception of the first column, which has been calculated, this table has been taken from Howe's "Metallurgical Laboratory Notes," page 127, by permission of the author.

Experiments 6, 7, and 8.

DETERMINATION OF MELTING POINTS.

Experiment 6.

Melting point of tin. — Melt about 500 grams of tin in a graphite crucible in a small gas furnace (see Fig. 7), keeping the metal covered with a deep layer of charcoal to prevent oxidation.

Description of apparatus for determining the melting points of metals. — The furnace, Fig. 7, is of sheet and cast iron with a thick lining, *L*, of fire clay. An inverted scorifier, *S*, supports the crucible, *XX*, which contains the metal, *MM*, to be tested. The molten metal is covered with a layer of charcoal, *cc*, to prevent oxidation of the metal. A cover for the crucible, *w'w'*, is helpful in preventing oxidation but not necessary. A fire-clay cover, *WW*, prevents wasteful loss of heat and keeps the top of the crucible hot. *RR* is the ring burner which supplies the mixture of air and gas to numerous tuyères, *tt*. A Le Chatelier thermo-couple is supported and protected by the porcelain tube, *P*, which is inserted into the molten metals, *MM*. *JJ* is the cold junction of the thermo-couple, immersed in a bottle of cold distilled water, *B*. The temperature of the water and therefore of the cold junction is determined by means of a thermometer, *T*.

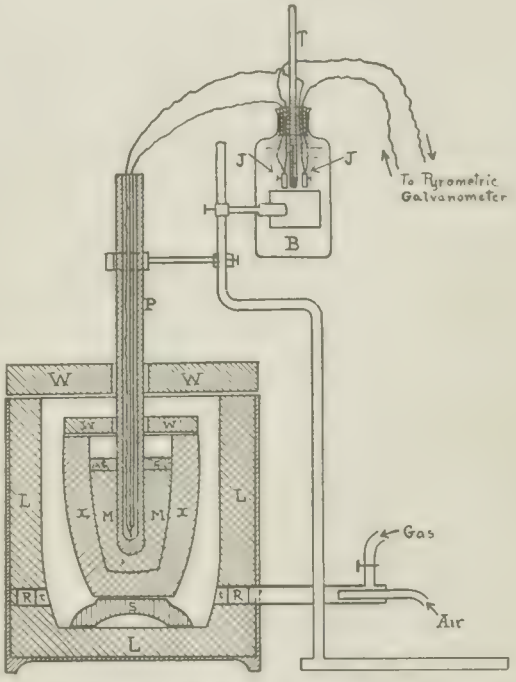


Fig. 7. — Apparatus for Determining the Melting Points of Metals.

Insert in the molten tin the couple of a Le Chatelier pyrometer enclosed in a porcelain tube.

Allow the molten tin to cool and ascertain carefully the rate of cooling by noting the time required for the bath to cool every 10° C., or every 25° F., beginning with 350° C. (or 650° F.) and ending at 100° C. (or 200° F.). The solidification will be indicated by a marked and quite sudden retardation in the rate of cooling. Again apply heat and observe the rate of heating in the same manner, from 100° to 350° C. The melting point will be indicated by a marked retardation in the rate of heating. It should agree closely with the solidification point.

Experiment 7.

Melting point of lead. — Ascertain the melting point and the solidification point of lead in exactly the same manner as in experiment 6, recording the time between 200° C. (or 400° F.) and 450° C. (or 850° F.).

Experiment 8.

Melting point of zinc. — Ascertain the melting point and the solidification point of zinc in exactly the same manner, recording the time between 300° C. (575° F.) and 550° C. (1025° F.).

In every case the figures obtained should be corrected for the temperature of the cold junction.

TABLE 6. — MELTING POINTS OF METALS. (From the latest available data.)[1]

METAL.	MELTING POINT.	
	Deg. C.	Deg. F.
Sn	232	450
Bi	269	516
Cd	322	611
Pb	327	620
Zn	419	786
Sb	631	1168
Al	657	1215
Ag (in air)	955	1750
Ag (pure)	962	1763
Au	1064	1947
Cu (in air)	1065	1949
Cu (pure)	1084	1983
Mn[2] (98–99%)	1207	2204
Ni[2] (99.95%)	1435	2615
Co[2] (99.95%)	1464	2667
Cr[2] (98–99%)	1489	2712
Fe[3]	1519	2766

[1] The values for the melting points are given only to the nearest degree. They have been chosen from the table given in "High Temperature Measurements," by Le Chatelier-Boudouard-Burgess, 1904, page 303. Harker, "Electrochemical and Metallurgical Industry," Vol. 5, 1907, page 48, gives practically the same values in every case, with the exception of tin, which he gives as 224° C. For a valuable table of melting points and other important temperatures, see Howe's "Metallurgical Laboratory Notes," 1902, pages 124 and 125.

[2] These values are taken from "Melting Points of the Iron Group Elements by a New Radiation Method," by G. K. Burgess, Bulletin of the United States Bureau of Standards, Vol. 3, No. 3, page 353.

[3] "The Freezing-Point of Iron," H. C. H. Carpenter, presented at the September, 1908, meeting of the Iron and Steel Institute.

Experiment 6.

DATA FOR DETERMINING THE SOLIDIFICATION POINT AND THE MELTING POINT OF TIN.

COOLING.			HEATING.			COOLING.			HEATING.		
Temperature Deg. C.	Time.	Difference.	Temperature Deg. C.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.
350			100			700			200		
340			110			675			225		
330			120			650			250		
320			130			625			275		
310			140			600			300		
300			150			575			325		
290			160			550			350		
280			170			525			375		
270			180			500			400		
260			190			475			425		
250			200			450			450		
240			210			425			475		
230			220			400			500		
220			230			375			525		
210			240			350			550		
200			250			325			575		
190			260			300			600		
180			270			275			625		
170			280			250			650		
160			290			225			675		
150			300			200			700		
140			310								
130			320								
120			330								
110			340								
100			350								

Experiment 7.

DATA FOR DETERMINING THE SOLIDIFICATION POINT AND THE MELTING POINT OF LEAD.

COOLING.			HEATING.			COOLING.			HEATING.		
Temperature Deg. C.	Time.	Difference	Temperature Deg. C.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.
450			200			900			400		
440			210			875			425		
430			220			850			450		
420			230			825			475		
410			240			800			500		
400			250			775			525		
390			260			750			550		
380			270			725			575		
370			280			700			600		
360			290			675			625		
350			300			650			650		
340			310			625			675		
330			320			600			700		
320			330			575			725		
310			340			550			750		
300			350			525			775		
290			360			500			800		
280			370			475			825		
270			380			450			850		
260			390			425			875		
250			400			400			900		
240			410								
230			420								
220			430								
210			440								
200			450								

Experiment 8.

DATA FOR DETERMINING THE SOLIDIFICATION POINT AND THE MELTING POINT OF ZINC.

COOLING.			HEATING.			COOLING.			HEATING.		
Temperature Deg. C.	Time.	Difference.	Temperature Deg. C.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.
550			300			1000			500		
540			310			975			525		
530			320			950			550		
520			330			925			575		
510			340			900			600		
500			350			875			625		
490			360			850			650		
480			370			825			675		
470			380			800			700		
460			390			775			725		
450			400			750			750		
440			410			725			775		
430			420			700			800		
420			430			675			825		
410			440			650			850		
400			450			625			875		
390			460			600			900		
380			470			575			925		
370			480			550			950		
360			490			525			975		
350			500			500			1000		
340			510								
330			520								
320			530								
310			540								
300			550								

Experiments 6, 7, and 8.

LABORATORY REPORT.

PYROMETRY*—*Determination of Melting Points.

SUBSTANCE USED.		Reading.	Correction for Cold Junction.	Corrected Reading.	
				Deg. C.	Deg. F.
Tin	Solidification				
	Melting				
Lead	Solidification				
	Melting				
Zinc	Solidification				
	Melting				

Remarks: *Date:*

Experiments 9 to 13.

REDUCTION OF METALLIC COMPOUNDS.

1. *Reduction of Oxides by Carbon.*

Experiment 9.

Reduction of copper oxide by carbon. — Copper oxide (CuO) is reduced to the metallic state by heating it in contact with carbon according to the following reactions:

$$(1)\quad CuO + C = Cu + CO.$$
$$(2)\quad CuO + CO = Cu + CO_2.$$

When the temperature is high, as in the interior of a blast furnace, reaction (1) is probably the only one taking place in the presence of excess carbon, because CO_2 cannot exist, and therefore cannot be formed, above 1000° C. At the top of the blast furnace, however, and wherever, as in our case, the temperature is gradually raised from the cold, reaction (2) takes place to a large extent, the CO being obtained from reaction (1).

The relative weights of copper oxide and carbon for this experiment [1] are, therefore, based on the assumption that reactions (1) and (2) both take place.

For this experiment, and Experiments 10, 12, and 13, a gas furnace (preferably of the muffle type) is recommended, it being easier by this means to regulate the temperature during the reduction.

Procedure. — Weigh 100 grams of black oxide of copper (CuO) and mix it with 10 grams of charcoal in a clay crucible, using a spatula or knife to insure thorough mixing.

Cover the crucible and place it in a furnace, which for convenience has already been lighted.

Raise the temperature as rapidly as possible until the furnace has reached a temperature of 1100° C.

Continue the heating for one hour after this temperature is reached.

Pour the contents of the crucible in an iron mold, covering it immediately with a layer of charcoal to prevent reoxidation of the metal.

When cold, weigh the copper button.

Figure out the amount of copper in the charge and the percentage of the metal reduced.

In addition to writing the chemical reaction in equation form, using the relative or combining weights, write the heat equation corresponding to the reaction, indicating the net heat absorbed or given out, and state whether the reaction is endothermic or exothermic (see Table 7).

[1] It has been found that with the amount of charcoal called for by reaction (1), namely, 15 + grams, reduction takes place, but the resulting metallic copper occurs in fine beads or even dust scattered through the excess of charcoal, while the procedure described here gives a solid metallic button containing all the reduced copper and easily poured and weighed.

Experiment 10.

Reduction of lead oxide by carbon. - Lead oxide (PbO) is reduced to the metallic state by heating it in contact with carbon according to the following reaction:[1]

$$2PbO + C = 2Pb + CO_2.$$

Weigh 200 grams of PbO (litharge) and mix thoroughly with 8 grams of charcoal.

Place this mixture in a clay crucible. Cover the crucible and place it in the furnace.

Continue the heating for one hour after the furnace has reached a temperature of 900° C.

Pour the contents of the crucible carefully into an iron mold and when cold weigh the lead button.

Figure out the amount of lead in the charge and the percentage of the metal reduced and report as in Experiment 9.

TABLE 7. — THERMOCHEMICAL DATA.[2]

Atomic weights of the elements and molecular heats of formation of the compounds involved in the reduction experiments.

ATOMIC WEIGHTS.		FORMULA	MOLECULAR HEAT OF FORMATION CALORIES.
Al	27	(C, O)	29,160
C	12	(C, O_2)	97,200
Cu	63.6	(Cu, O)	37,700
Fe	56	(Pb, O)	50,800
O	16	(Al_2, O_3)	392,600
Pb	207	(Fe_3, O_4)	270,800
S	32	(Fe_2, O_3)	195,600
		(Pb, S)	20,200
		(Cu_2, S)	20,300
		(S, O_2)	69,260

[1] This reaction is really a combination of the two reactions, (1) PbO + C = Pb + CO, and (2) PbO + CO = Pb + CO_2, but since the temperature in this case never rises above 1000° C., carbon dioxide has no difficulty in forming. The reaction is given, therefore, in its simplest form, notwithstanding the fact that in the presence of excess carbon there may be some CO in the waste gases due to the reduction of CO_2 by C.

[2] These values are quoted from a much larger list in "Metallurgical Calculations," by J. W. Richards, 1906, Vol. I, page 1 and pages 15 to 18.

Experiment 9.

LABORATORY REPORT.

Reduction of Metallic Compounds.

Name of Metallic Compound:

Name of Reducing Agent:

Chemical Reaction:
(Indicate both relative weights and heat of formation)

Weight of the Metallic Compound:

Weight of the Reducing Agent:

Weight of Metal in the Charge:

Weight of Metal reduced:

Percentage of Metal reduced:

Remarks: *Date:*

Experiment 10.

LABORATORY REPORT.

Reduction of Metallic Compounds.

Name of Metallic Compound:

Name of Reducing Agent:

Chemical Reaction:
(Indicate both relative weights and heat of formation)

Weight of the Metallic Compound:

Weight of the Reducing Agent:

Weight of Metal in the Charge:

Weight of Metal reduced:

Percentage of Metal reduced:

Remarks: *Date:*

2. *Reduction of Oxides by Metals.*

Experiment 11.

The thermit reaction.[1] - Because of the very great affinity of aluminum for oxygen, we can reduce metallic oxides by making an intimate mixture of the powdered oxide and powdered aluminum and bringing one part of the mass to the temperature necessary to start the reaction. The reaction being powerfully exothermic, no further application of heat is required once it has been started.

Weigh 200 grams of an intimate mixture, called "Thermit," of iron oxides and powdered aluminum, into a special crucible.[2]

Place on top of the mixture a teaspoonful of ignition powder.

Ignite the powder by means of a bengal match or by some other suitable means.

Note the intensity of the reaction and the high temperature produced.

Pour into a cast-iron mold.

The reaction is probably as follows:

$$3Fe_3O_4 + 8Al = 9Fe + 4Al_2O_3.$$[3]

Assuming that the Fe_3O_4 and Al are present in the mixture in molecular proportions, figure out the amount of iron in the charge and the percentage of the metal reduced and report in the usual way.

---

[1] Discovered by Dr. Hans Goldschmidt, Essen-Ruhr, Germany, and patented by him in 1895.

[2] "Thermit" mixture, ignition powder, and special crucibles made of sheet iron and heavily lined with magnesia may be obtained from the Goldschmidt Thermit Company, New York.

[3] This equation is given on our own responsibility, and without the authorization of the patentee. The equation $Fe_2O_3 + 2Al = 2Fe + Al_2O_3$ is also possible, doubtless, as are many other thermit reactions.

Experiment 11.

LABORATORY REPORT.

Reduction of Metallic Compounds.

Name of Metallic Compound:

Name of Reducing Agent:

Chemical Reaction:
(Indicate both relative weights and heat of formation)

Weight of the Metallic Compound:

Weight of the Reducing Agent:

Weight of Metal in the Charge:

Weight of Metal reduced:

Percentage of Metal reduced:

Remarks: *Date:*

3. Reduction of Oxides by Sulphides.

Experiment 12.

Reduction of copper oxide by copper sulphide. — Copper oxide (CuO) and copper sulphide (Cu_2S) are reduced to the metallic state by heating them together according to the reaction

$$2CuO + Cu_2S = 4Cu + SO_2.$$

Weigh 50 grams of black oxide of copper (CuO) and mix thoroughly with 50 grams of copper sulphide (Cu_2S) in a small clay crucible (size No. 10).

Cover the crucible and place it in the furnace.

Continue the heating for one hour after the furnace has reached a temperature of 1100° C.

Pour the contents of the crucible carefully into an iron mold, covering the metal immediately with powdered charcoal as in Experiment 9.

When cold, weigh the copper button.

Figure out the amount of copper in the charge and the percentage of the metal reduced. Report in the usual way.

Experiment 13.

Reduction of lead oxide by lead sulphide. — Lead oxide (PbO) and lead sulphide (PbS) are reduced to the metallic state by heating them together according to the following reaction:

$$PbS + 2PbO = 3Pb + SO_2.$$

Weigh 100 grams of PbO (litharge) and mix thoroughly with 53 grams of PbS (galena) in a large clay crucible.

Cover the crucible and place it in the furnace.

Continue the heating for one hour after the temperature of the furnace has reached 900° C.

Pour the contents of the crucible carefully into an iron mold and when cold weigh the lead button.

Figure out the amount of lead in the charge and the percentage of the metal reduced. Report in the usual way.

Experiment 12.

LABORATORY REPORT.

Reduction of Metallic Compounds.

Name of Metallic Compound:

Name of Reducing Agent:

Chemical Reaction:
(Indicate both relative weights and heat of formation)

Weight of the Metallic Compound:

Weight of the Reducing Agent:

Weight of Metal in the Charge:

Weight of Metal reduced:

Percentage of Metal reduced:

Remarks: *Date:*

Experiment 13.

LABORATORY REPORT.

Reduction of Metallic Compounds.

Name of Metallic Compound:

Name of Reducing Agent:

Chemical Reaction:
(Indicate both relative weights and heat of formation)

Weight of the Metallic Compound:

Weight of the Reducing Agent:

Weight of Metal in the Charge:

Weight of Metal reduced:

Percentage of Metal reduced:

Remarks: *Date:*

PART II. METALLURGY OF IRON AND STEEL.

Experiment 14.

TO ILLUSTRATE THE INFLUENCE OF CARBON UPON THE TENACITY, ELASTICITY, AND DUCTILITY OF IRON.

Material. — Each squad will be supplied with one bar of wrought iron and with three bars of steel containing respectively about 0.10, 0.30, and 0.50 per cent of carbon, and of suitable dimensions to be tested in the testing-machine.

Measurements. — A length of four inches should be carefully measured in the middle of each bar and two punch marks[1] made exactly four inches apart. This distance is called the gauged length. The cross section of each bar should be carefully measured by means of micrometer calipers and its area in square inches (see Table 8, page 351) should be written in the proper column of the printed blanks provided for recording the data of this experiment (see page 36).

Testing. — Each bar will now be placed in turn in a suitable testing-machine and a gradually increasing load applied until rupture occurs. The instructor in charge will explain to the students the handling and running of the testing machine.

Elastic limit. — While the load is gradually increasing the beam should be kept as nicely balanced as possible by suitable handling of the poise which travels over it. When a certain load is reached the beam will quite suddenly drop and will fail to rise again for awhile. This occurrence is called the "fall of the beam," and the corresponding stress indicates the "yield point" or the approximate elastic limit of the test bar. It should be recorded in the proper column of the printed form.

Tensile strength. — The test should now be continued until fracture takes place, and the breaking load properly recorded. It corresponds to the tensile strength of the bar.

Elongation. — The two fragments of each bar should now be removed from the machine and fitted together as closely as possible, and the distance between the two punch marks carefully measured and recorded. The amount of stretch or elongation indicates the ductility of the metal.

Elastic limit and tensile strength per square inch. — From the figures previously recorded and indicating the actual elastic limit and tensile strength of the bar tested, the same properties should now be calculated per square inch of a similar metal, and duly recorded in the columns reserved for them.

Elongation per cent. — The amount of elongation should be calculated in percentage of the original gauged length.

[1] The use of an automatic punch insures constant depth and size of the punch marks.

Reduction of area. — The cross section of the bars will be found reduced near the fracture, and this reduced section should be measured and calculated in square inches and the percentage of reduction figured and duly recorded. The amount of reduction is an indication of the ductility of the metal.

Fracture. — In the column headed "Remarks," the appearance of the fracture should be indicated; fractures are generally classified as fibrous, coarsely crystalline, finely crystalline, and silky.

Experiment 15.

TO ILLUSTRATE THE INFLUENCE OF CARBON UPON THE TENACITY, ELASTICITY, AND DUCTILITY OF IRON; ALSO THE INFLUENCE OF NICKEL UPON THESE PROPERTIES.

Material. — Each squad will be provided with two bars of steel containing respectively about 1.00 and 1.25 per cent of carbon and with one bar of nickel steel containing about 0.30 per cent of carbon and 3.50 per cent of nickel.

Testing. — The tenacity, elasticity, and ductility of these bars should be ascertained and recorded exactly as in the preceding experiment.

Plotting. — The results of these two experiments should be plotted on a sheet of plotting paper, with the carbon content as abscissae and the tenacity and elastic limit (in pounds per square inch) and the elongation (in percentage) as ordinates.

Conclusions. — These experiments should teach that wrought iron is a very ductile but only moderately strong metal and that its elastic limit is generally a little more than half its tenacity. It breaks with a coarse, irregular fracture. As the carbon increases the tensile strength of the metal also increases. The steel bar containing 1.25 per cent of carbon, however, is liable to be less tenacious than the bar containing some 1 per cent of that element, indicating that steel of maximum tenacity contains generally about 1 per cent of carbon. The elastic limit, on the contrary, will be found to increase continuously with the carbon content. In the softest steel it is a little more than one half the tenacity, but as the carbon increases it approaches more and more the tensile strength.

The ductility will be found to diminish as the proportion of carbon increases, thus illustrating the fact that great tenacity and much ductility cannot readily be combined in the same sample of carbon steel.

The fracture of the softest steel will be found irregular generally, and somewhat coarsely crystalline. As the carbon increases it will become more regular in shape and more finely crystalline.

The tests will further teach that the effect of nickel is to greatly raise the tenacity and especially the elastic limit of the steel, while retaining the original ductility, thus combining in a remarkable degree strength and ductility, from which the value of nickel steel will be apparent.

A copy of the graphical statement should be pasted in this book on the blank page opposite page 36. Another copy should be handed to the instructor.

TABLE 8.

Riehlé Bros. Testing Machine Co.

ESTABLISHED 1865

ENGINEERS — FOUNDERS — MACHINISTS

Office and Works—1424 North Ninth Street, Philadelphia, Pa., U. S. A.

TESTING DEPARTMENT

Diameters of Circles in Thousandths of an Inch with their Areas in Square Inches

Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area	Dia.	Area
.001	.0000008	.101	.0080012	.201	.0317309	.301	.0711580	.401	.126293	.501	.197113	.601	.283687	.701	[illegible]	.801	.503913	.901	[illegible]
.002	.0000031	.102	.008171	.202	.0320474	.302	.0716316	.402	.126924	.502	.197923	.602	.284632	.702	.387048	.802	.505172	.902	.639004
.003	.0000071	.103	.0083432	.203	.0323655	.303	.0721067	.403	.127556	.503	.198713	.603	.285578	.703	.388151	.803	.506432	.903	.640422
.004	.0000126	.104	.0085195	.204	.0326852	.304	.0725835	.404	.128189	.504	.199504	.604	.286526	.704	.389256	.804	.507693	.904	.641841
.005	.0000196	.105	.0086959	.205	.0330064	.305	.0730618	.405	.128825	.505	.200296	.605	.287476	.705	.390363	.805	.508958	.905	.643262
.006	.0000283	.106	.0088725	.206	.0333292	.306	.0735417	.406	.129462	.506	.201090	.606	.288426	.706	.391471	.806	.510224	.906	.644684
.007	.0000385	.107	.0089992	.207	.0336536	.307	.0740231	.407	.130100	.507	.201886	.607	.289379	.707	[illegible]	.807	.511490	.907	.646108
.008	.0000503	.108	.0091611	.208	.0339795	.308	.0745061	.408	.130740	.508	.202683	.608	.290324	.708	.394694	.808	.512759	.908	.647534
.009	.0000636	.109	.0093331	.209	.0343070	.309	.0749907	.409	.131382	.509	.203482	.609	.291289	.709	.394805	.809	.514029	.909	.648961
.010	.0000785	.110	.0095053	.210	.0346361	.310	.0754769	.410	.132025	.510	.204282	.610	.292247	.710	[illegible]	.810	.515300	.910	.650389
.011	.0000950	.111	.0096777	.211	.0349667	.311	.0759646	.411	.132670	.511	.205084	.611	.293206	.711	[illegible]	.811	.516574	.911	.651819
.012	.0001131	.112	.0098502	.212	.0352990	.312	.0764539	.412	.133316	.512	.205887	.612	.294166	.712	[illegible]	.812	.517848	.912	.653251
.013	.0001327	.113	.0100287	.213	.0356328	.313	.0769448	.413	.133964	.513	.206692	.613	.295128	.713	.399273	.813	.519125	.913	.654685
.014	.0001539	.114	.0102070	.214	.0359681	.314	.0774372	.414	.134614	.514	.207499	.614	.296092	.714	.400393	.814	.520402	.914	.656120
.015	.0001767	.115	.0103859	.215	.0363051	.315	.0779313	.415	.135265	.515	.208307	.615	.297057	.715	.401516	.815	.521682	.915	.657556
.016	.0002011	.116	.0105653	.216	.0366436	.316	.0784268	.416	.135918	.516	.209117	.616	.298024	.716	.402640	.816	.522964	.916	.658994
.017	.0002270	.117	.0107514	.217	.0369837	.317	.0789240	.417	.136572	.517	.209928	.617	.298993	.717	.403765	.817	.524248	.917	.660434
.018	.0002545	.118	.0109389	.218	.0373253	.318	.0794227	.418	.137228	.518	.210741	.618	.299963	.718	.404892	.818	.525533	.918	.661875
.019	.0002835	.119	.0111220	.219	.0376685	.319	.0799230	.419	.137885	.519	.211556	.619	.300934	.719	.406021	.819	.526815	.919	.663318
.020	.0003142	.120	.0113097	.220	.0380133	.320	.0804249	.420	.138544	.520	.212372	.620	.301907	.720	.407151	.820	.528102	.920	.664762
.021	.0003464	.121	.0114990	.221	.0383597	.321	.0809284	.421	.139205	.521	.213189	.621	.302882	.721	.408283	.821	.529391	.921	.666208
.022	.0003801	.122	.0116898	.222	.0387076	.322	.0814334	.422	.139867	.522	.214008	.622	.303858	.722	.409416	.822	.530682	.922	.667655
.023	.0004155	.123	.0118823	.223	.0390571	.323	.0819399	.423	.140530	.523	.214829	.623	.304836	.723	[illegible]	.823	.531974	.923	.669105
.024	.0004524	.124	.0120763	.224	.0394082	.324	.0824481	.424	.141196	.524	.215651	.624	.305815	.724	.411687	.824	.533267	.924	.670556
.025	.0004909	.125	.0122718	.225	.0397608	.325	.0829578	.425	.141862	.525	.216475	.625	.306796	.725	.412825	.825	.534562	.925	.672007
.026	.0005309	.126	.0124690	.226	.0401150	.326	.0834691	.426	.142531	.526	.217301	.626	.307779	.726	.413965	.826	.535860	.926	.673461
.027	.0005726	.127	.0126677	.227	.0404708	.327	.0839820	.427	.143201	.527	.218128	.627	.308763	.727	.415106	.827	.537157	.927	.674916
.028	.0006158	.128	.0128679	.228	.0408282	.328	.0844964	.428	.143872	.528	.218956	.628	.309749	.728	.416249	.828	.538457	.928	.676373
.029	.0006605	.129	.0130698	.229	.0411871	.329	.0850124	.429	.144545	.529	.219787	.629	.310736	.729	.417393	.829	.539759	.929	.677832
.030	.0007069	.130	.0132732	.230	.0415476	.330	.0855300	.430	.145220	.530	.220618	.630	.311725	.730	.418539	.830	.541062	.930	.679292
.031	.0007548	.131	.0134782	.231	.0419097	.331	.0860492	.431	.145896	.531	.221452	.631	.312715	.731	.419687	.831	.542366	.931	.680754
.032	.0008042	.132	.0136848	.232	.0422733	.332	.0865699	.432	.146574	.532	.222287	.632	.313707	.732	.420836	.832	.543672	.932	.682217
.033	.0008553	.133	.0138929	.233	.0426385	.333	.0870922	.433	.147253	.533	.223124	.633	.314701	.733	.421986	.833	.544980	.933	.683682
.034	.0009079	.134	.0141026	.234	.0430053	.334	.0876160	.434	.147934	.534	.223961	.634	.315698	.734	.423138	.834	.546289	.934	.685148
.035	.0009621	.135	.0143139	.235	.0433737	.335	.0881415	.435	.148617	.535	.224801	.635	.316692	.735	.424292	.835	.547600	.935	.686616
.036	.0010179	.136	.0145267	.236	.0437436	.336	.0886685	.436	.149301	.536	.225642	.636	.317691	.736	.425448	.836	.548912	.936	.688085
.037	.0010752	.137	.0147411	.237	.0441151	.337	.0891970	.437	.149987	.537	.226485	.637	.318690	.737	.426604	.837	.550226	.937	.689556
.038	.0011341	.138	.0149571	.238	.0444881	.338	.0897272	.438	.150674	.538	.227329	.638	.319692	[illegible]	.427763	.838	.551542	.938	.691029
.039	.0011946	.139	.0151747	.239	.0448628	.339	.0902589	.439	.151362	.539	.228175	.639	.320695	.739	.428923	.839	.552859	.939	.692503
.040	.0012568	.140	.0153938	.240	.0452390	.340	.0907922	.440	.152053	.540	.229022	.640	.321699	.740	[illegible]	.840	.554178	.940	.693979
.041	.0013203	.141	.0156145	.241	.0456168	.341	.0913270	.441	.152745	.541	.229871	.641	.322705	.741	.431248	.841	[illegible]	.941	.695456
.042	.0013854	.142	.0158368	.242	.0459961	.342	.0918635	.442	.153438	.542	.230722	.642	.323713	.742	.432412	.842	.556820	.942	.696935
.043	.0014522	.143	.0160606	.243	.0463770	.343	.0924011	.443	.154133	.543	.231574	.643	.324722	.743	.433579	.843	.558143	.943	.698416
.044	.0015205	.144	.0162860	.244	.0467595	.344	.0929403	.444	.154830	.544	.232426	.644	.325733	.744	.434747	.844	.559468	.944	.699898
.045	.0015904	.145	.0165130	.245	.0471436	.345	.0934812	.445	.155528	.545	.233283	.645	.326746	.745	.435916	.845	[illegible]	.945	.701381
.046	.0016619	.146	.0167415	.246	.0475292	.346	.0940240	.446	.156228	.546	.234140	.646	.327759	.746	.437087	.846	.562123	.946	.702867
.047	.0017349	.147	.0169717	.247	.0479164	.347	.0945692	.447	.156929	.547	.234998	.647	.328775	.747	[illegible]	.847	.563453	.947	.704353
.048	.0018095	.148	.0172034	.248	.0483052	.348	.0951150	.448	.157632	.548	.235858	.648	.329792	.748	.439434	.848	.564784	.948	.705842
.049	.0018857	.149	.0174366	.249	.0486955	.349	.0956625	.449	.158337	.549	.236720	.649	.330811	.749	.440610	.849	.566117	.949	.707332
.050	.0019635	.150	.0176715	.250	.0490875	.350	.0962115	.450	.159043	.550	.237583	.650	.331831	.750	.441787	.850	.567451	.950	.708823
.051	.0020428	.151	.0179079	.251	.0494809	.351	.0967620	.451	.159751	.551	.238448	.651	.332853	.751	.442966	.851	.568787	.951	.710316
.052	.0021237	.152	.0181458	.252	.0498760	.352	.0973142	.452	.160460	.552	.239314	.652	.333876	.752	.444146	.852	.570125	.952	.711811
.053	.0022062	.153	.0183854	.253	.0502726	.353	.0978679	.453	.161171	.553	.240182	.653	.334901	.753	.445328	.853	.571464	.953	.713307
.054	.0022902	.154	.0186265	.254	.0506708	.354	.0984231	.454	.161884	.554	.241051	.654	.335928	.754	.446512	.854	.572804	.954	.714805
.055	.0023758	.155	.0188692	.255	.0510706	.355	.0989800	.455	.162597	.555	.241922	.655	.336956	.755	.447697	.855	.574147	.955	.716304
.056	.0024630	.156	.0191134	.256	.0514719	.356	.0995384	.456	.163312	.556	.242795	.656	.337985	.756	.448884	.856	[illegible]	.956	.717805
.057	.0025518	.157	.0193593	.257	.0518748	.357	.1000985	.457	.164030	.557	.243669	.657	.339017	.757	.450072	.857	.576836	.957	.719307
.058	.0026421	.158	.0196067	.258	.0522793	.358	.1006601	.458	.164748	.558	.244545	.658	.340049	.758	.451262	.858	.578183	.958	.720811
.059	.0027340	.159	.0198556	.259	.0526854	.359	.1012233	.459	.165468	.559	.245422	.659	.341084	.759	.452454	.859	.579531	.959	.722317
.060	.0028274	.160	.0201062	.260	.0530930	.360	.1017881	.460	.166190	.560	.246301	.660	.342120	.760	.453647	.860	.580881	.960	.723824
.061	.0029225	.161	.0203583	.261	.0535022	.361	.1023544	.461	.166913	.561	.247181	.661	.343157	.761	.454841	.861	.582233	.961	.725333
.062	.0030191	.162	.0206120	.262	.0539129	.362	.1029223	.462	.167638	.562	.248063	.662	.344196	.762	.456037	.862	.583586	.962	.726843
.063	.0031173	.163	.0208672	.263	.0543253	.363	.1034918	.463	.168365	.563	.248947	.663	.345247	.763	.457235	.863	.584941	.963	.728355
.064	.0032170	.164	.0211241	.264	.0547392	.364	.1040629	.464	.169093	.564	.249832	.664	.346279	.764	.458435	.864	.586297	.964	.729869
.065	.0033183	.165	.0213825	.265	.0551547	.365	.1046354	.465	.169823	.565	.250719	.665	.347323	.765	.459635	.865	.587655	.965	.731384
.066	.0034212	.166	.0216424	.266	.0555718	.366	.1052095	.466	.170554	.566	.251607	.666	.348368	.766	.460838	.866	.589015	.966	.732900
.067	.0035257	.167	.0219040	.267	.0559903	.367	.1057851	.467	.171287	.567	.252497	.667	.349416	.767	.462042	.867	.590377	.967	.734418
.068	.0036317	.168	.0221671	.268	.0564105	.368	.1063623	.468	.172021	.568	.253388	.668	.350464	.768	.463247	.868	.591739	.968	.735938
.069	.0037393	.169	.0224318	.269	.0568323	.369	.1069410	.469	.172757	.569	.254281	.669	.351514	.769	.464454	.869	.593103	.969	.737459
.070	.0038485	.170	.0226980	.270	.0572556	.370	.1075211	.470	.173494	.570	.255176	.670	.352566	.770	.465663	.870	.594469	.970	.738982
.071	.0039592	.171	.0229658	.271	.0576805	.371	.1081028	.471	.174233	.571	.256072	.671	.353619	.771	.466873	.871	.595836	.971	.740507
.072	.0040715	.172	.0232352	.272	.0581070	.372	.1086860	.472	.174974	.572	.256970	.672	.354674	.772	.468085	.872	.597205	.972	.742033
.073	.0041854	.173	.0235062	.273	.0585350	.373	.1092707	.473	.175716	.573	.257869	.673	.355730	.773	.469299	.873	.598576	.973	.743560
.074	.0043009	.174	.0237787	.274	.0589645	.374	.1098569	.474	.176460	.574	.258770	.674	.356788	.774	.470514	.874	.599948	.974	.745090
.075	.0044179	.175	.0240528	.275	.0593958	.375	.1104446	.475	.177205	.575	.259672	.675	.357847	.775	.471730	.875	.601321	.975	.746620
.076	.0045365	.176	.0243285	.276	.0598286	.376	.1110338	.476	.177952	.576	.260576	.676	.358909	.776	.472949	.876	.602697	.976	.748153
.077	.0046566	.177	.0246057	.277	.0602629	.377	.1116245	.477	.178701	.577	.261482	.677	.359971	.777	.474168	.877	.604073	.977	.749687
.078	.0047784	.178	.0248846	.278	.0606988	.378	.1122167	.478	.179451	.578	.262389	.678	.361035	.778	.475390	.878	.605452	.978	.751222
.079	.0049017	.179	.0251650	.279	.0611363	.379	.1128105	.479	.180202	.579	.263298	.679	.362101	.779	.476612	.879	.606832	.979	.752759
.080	.0050266	.180	.0254469	.280	.0615753	.380	.1134058	.480	.180956	.580	.264208	.680	.363168	.780	.477837	.880	.608213	.980	.754298
.081	.0051530	.181	.0257304	.281	.0620159	.381	.1140027	.481	.181710	.581	.265120	.681	.364237	.781	.479063	.881	.609596	.981	.755838
.082	.0052810	.182	.0260155	.282	.0624581	.382	.1146011	.482	.182467	.582	.266033	.682	.365308	.782	.480290	.882	.610981	.982	.757380
.083	.0054106	.183	.0263022	.283	.0629019	.383	.1152009	.483	.183225	.583	.266949	.683	.366380	.783	.481520	.883	.612367	.983	.758923
.084	.0055418	.184	.0265905	.284	.0633472	.384	.1158023	.484	.183984	.584	.267865	.684	.367454	.784	.482750	.884	.613755	.984	.760468
.085	.0056745	.185	.0268803	.285	.0637941	.385	.1164051	.485	.184745	.585	.268783	.685	.368529	.785	.483983	.885	.615144	.985	.762014
.086	.0058088	.186	.0271716	.286	.0642425	.386	.1170095	.486	.185508	.586	.269703	.686	.369606	.786	.485216	.886	.616535	.986	.763562
.087	.0059447	.187	.0274646	.287	.0646926	.387	.1176154	.487	.186272	.587	.270624	.687	.370684	.787	.486452	.887	.617928	.987	.765119
.088	.0060821	.188	.0277591	.288	.0651442	.388	.1182227	.488	.187038	.588	.271547	.688	.371764	.788	.487689	.888	.619322	.988	.766663
.089	.0062212	.189	.0280552	.289	.0655973	.389	.1188315	.489	.187805	.589	.272471	.689	.372845	.789	.488927	.889	.620718	.989	.768216
.090	.0063617	.190	.0283529	.290	.0660521	.390	.1194419	.490	.188574	.590	.273397	.690	.373928	.790	.490168	.890	.622115	.990	.769770
.091	.0065039	.191	.0286521	.291	.0665084	.391	.1200537	.491	.189345	.591	.274325	.691	.375013	.791	.491409	.891	.623514	.991	.771326
.092	.0066476	.192	.0289529	.292	.0669663	.392	.1206671	.492	.190117	.592	.275254	.692	.376099	.792	.492653	.892	.624914	.992	.772883
.093	.0067929	.193	.0292553	.293	.0674258	.393	.1212820	.493	.190890	.593	.276185	.693	.377187	.793	.493898	.893	.626316	.993	.774442
.094	.0069398	.194	.0295593	.294	.0678868	.394	.1218985	.494	.191665	.594	.277117	.694	.378276	.794	.495144	.894	.627720	.994	.776003
.095	.0070882	.195	.0298648	.295	.0683494	.395	.1225164	.495	.192442	.595	.278051	.695	.379367	.795	.496392	.895	.629126	.995	.777565
.096	.0072382	.196	.0301719	.296	.0688136	.396	.1231359	.496	.193220	.596	.278986	.696	.380460	.796	.497642	.896	.630531	.996	.779129
.097	.0073898	.197	.0304805	.297	.0692793	.397	.1237570	.497	.194000	.597	.279923	.697	.381554	.797	.498893	.897	.631939	.997	.780694
.098	.0075430	.198	.0307908	.298	.0697466	.398	.1243796	.498	.194782	.598	.280862	.698	.382650	.798	.500145	.898	.633349	.998	.782261
.099	.0076977	.199	.0311026	.299	.0702155	.399	.1250037	.499	.195565	.599	.281802	.699	.383747	.799	.501400	.899	.634761	.999	.783829
.100	.0078540	.200	.0314160	.300	.0706860	.400	.1256294	.500	.196350	.600	.282744	.700	.384846	.800	.502656	.900	.636174	1.000	.785400

Experiments 14 and 15.

LABORATORY REPORT.

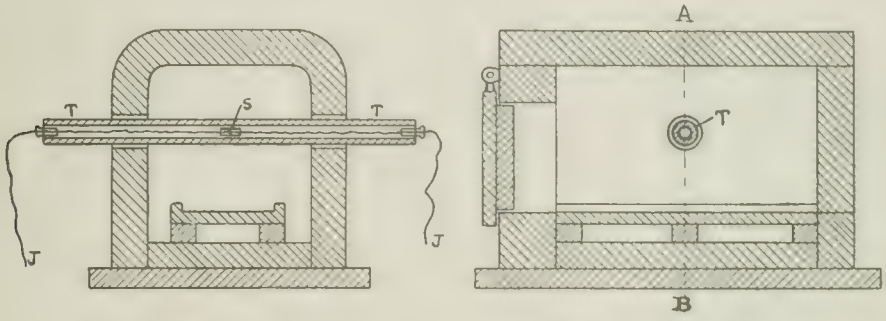
Illustrating the Influence of Carbon upon the Tenacity, Elasticity, and Ductibility of Iron; also the Effect of Nickel upon these Properties.

Material Tested.	Marked.	Dimension of Test Piece.		Area of Section in Sq. In.	Elastic Limit in Lbs.	Maximum Load in Lbs.	Elongation in In.	Reduced Cross Section.	Area of Reduced Section in Sq. In.	**Elastic Limit** per Sq. In. in Lbs.	**Tensile Strength** per Sq. In. in Lbs.	**Elongation** Per Cent. of Gauged Length.	**Reduction** of Sectional Area Per Cent.	REMARKS.
		Length.	Cross Section.											

Experiment 16.

THE THERMAL CRITICAL POINTS OF STEEL.

Procedure. — Each squad will cut from stock bars containing about 1 per cent of carbon a piece measuring 1 inch in length. A small hole should be drilled through the center of this piece $\frac{1}{8}$ inch in diameter. The steel should now be placed in a furnace and the wires of the pyrometer couple carefully inserted in the piece so that the twisted end or hot junction will be in the center.



Vertical Cross Section on AB. Fig. 8. Vertical Longitudinal Section.

Fig. 8. *Tube-furnace for determining critical points of steel.* — This is a means devised by the authors for converting an ordinary gas-forge or slab-furnace into a tube-furnace. Holes of the proper diameter are bored in opposite sides of the gas-forge and a porcelain tube, *TT*, inserted. An ordinary electrician's porcelain bushing makes a good tube. The internal diameter of the tube should not be less than $\frac{3}{8}$ inch. Porcelain or cork plugs at the end of the tube prevent circulation of air through the tube, with consequent irregular heating and oxidation of the test-piece. The position of the test-piece is shown at *S*, the hot junction of the thermo-couple being in the center of the piece. *JJ* is the cold-junction. If the temperature of the cold-junction is to be observed, it is obvious that the couple must be a long one. If this is not convenient, then two water bottles must be used in which the water is kept at the same temperature. Several tubes may be arranged in a single gas-forge. The convenience of this device far outweighs any disadvantage in its use.

Light the furnace, and when a temperature of 500° C. (or 900° F.) is reached, note and record carefully the time required for each rise of temperature of 10° C. (or 25° F.). When a temperature of 900° C. (or 1650° F.) is attained, discontinue the supply of heat and record in a similar way the fall of temperature until the pyrometer registers 500° C. (or 900° F.). In this way the rate of heating and cooling of the piece of steel has been ascertained.

It will be found that on heating, somewhere between 675° and 775° C. (1250° and 1425° F.) there is a sudden and very marked retardation in the rise of temperature, which corresponds to the thermal critical point known as $Ac_{3\text{-}2\text{-}1}$ of the steel; it indicates an absorption of heat which is the outward manifestation of a critical transformation taking place within the metal. After a short while the rise of temperature again becomes normal. In cooling a similar retardation will be detected between 650° and 750° C. (1200° and 1400° F.), generally some 50° to 75° C. lower than the critical point on heating. This retardation is due to a spontaneous evolution of heat, which marks the opposite phase of the transformation occurring on heating. The critical point on cooling is called $Ar_{3\text{-}2\text{-}1}$.

Experiment repeated. — The same experiment should now be repeated with a piece of steel containing about 0.50 per cent of carbon. It will be found that the critical points, of which there are two on heating, called respectively Ac_1 and $Ac_{3\text{-}2}$, and two on cooling, called $Ar_{3\text{-}2}$ and Ar_1, are not so marked, and they will probably occur at a somewhat higher temperature, the influence of carbon being to increase the intensity of the retardations and to lower somewhat their position.

Plotting. — The readings obtained in these two experiments should now be carefully plotted with the time (in seconds) elapsed between readings as abscissæ and the temperatures as ordinates.

The resulting heating and cooling curves of these samples will forcibly illustrate the marked retardations which take place and which play such an important part in the rational treatment of steel. A copy of the heating and cooling curves should be pasted in this book opposite the corresponding datum sheet and another copy handed to the instructor.

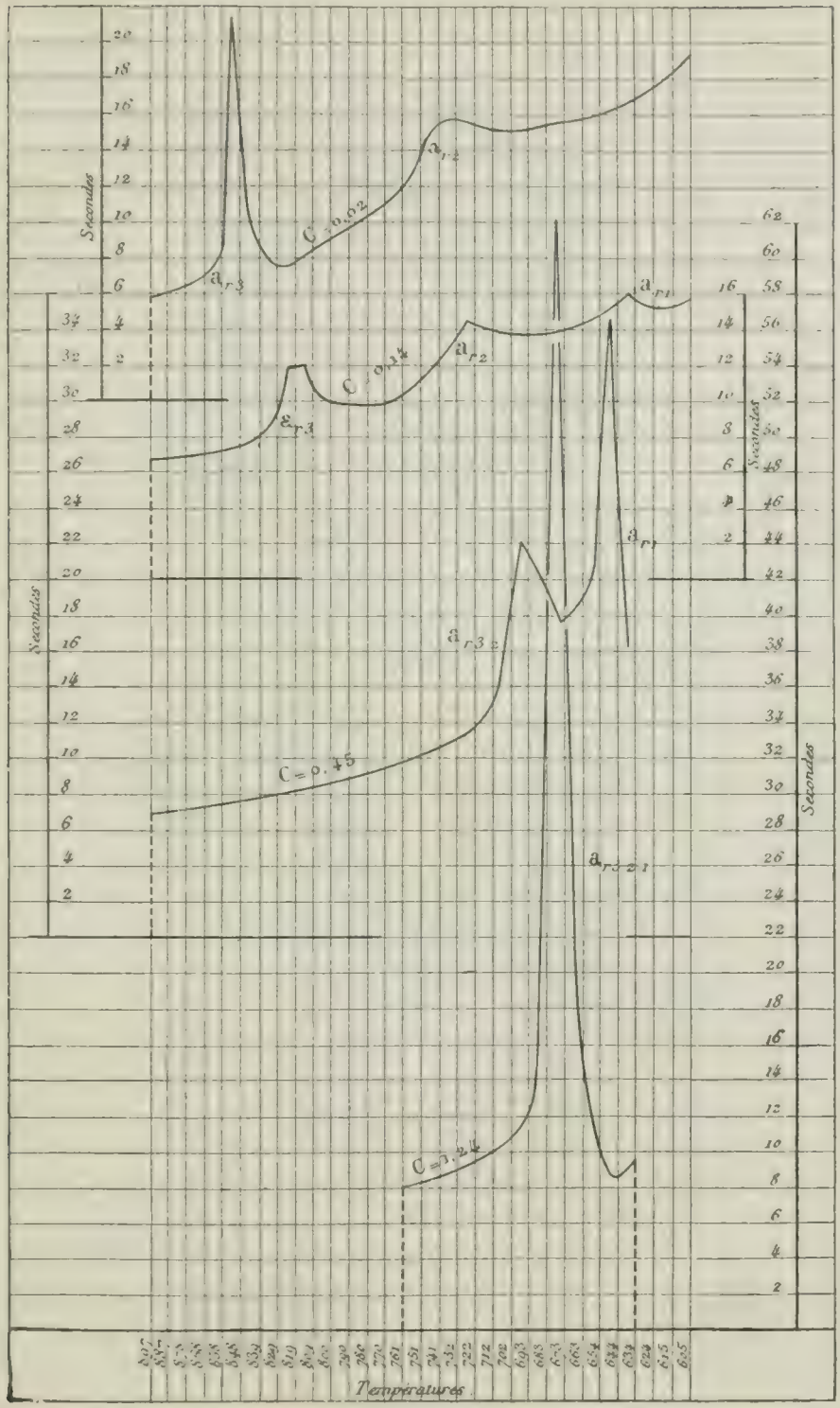


Fig. 9. — Cooling Curves of Steels containing respectively 0.02, 0.14, 0.45 and 1.24 per cent Carbon. (Osmond.)

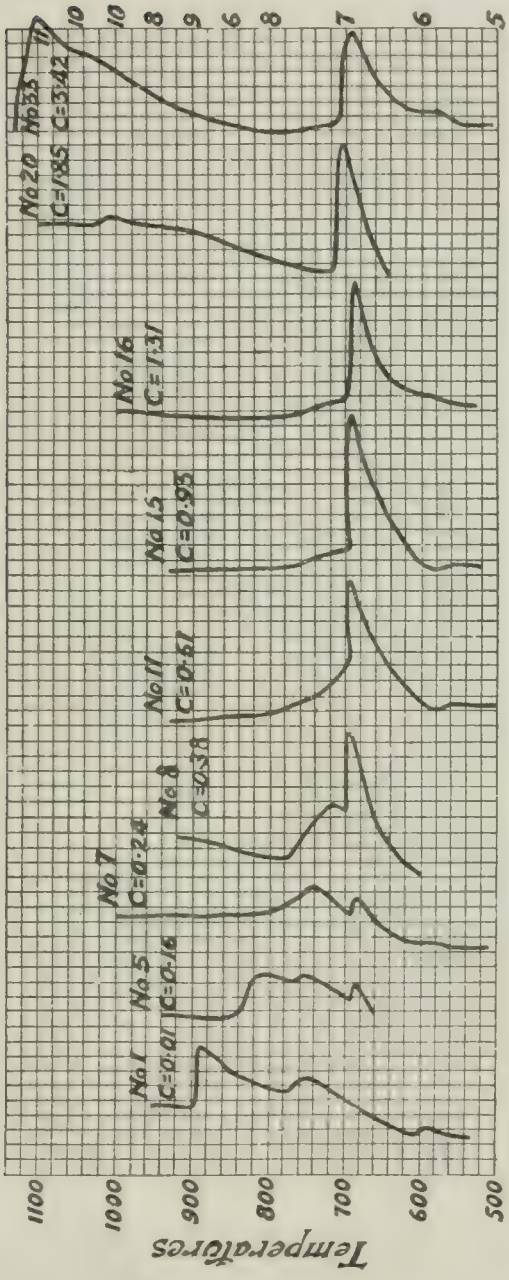


Fig. 10. — Cooling Curves of Very Pure Iron-Carbon Alloys (after Carpenter and Keeling). Reproduced from the "Iron and Steel Magazine," Vol. VII, 1904, page 637. See also the "Journal of the Iron and Steel Institute" for May, 1904.
The critical points obtained from these typical curves are included with those used in plotting Fig. 11.

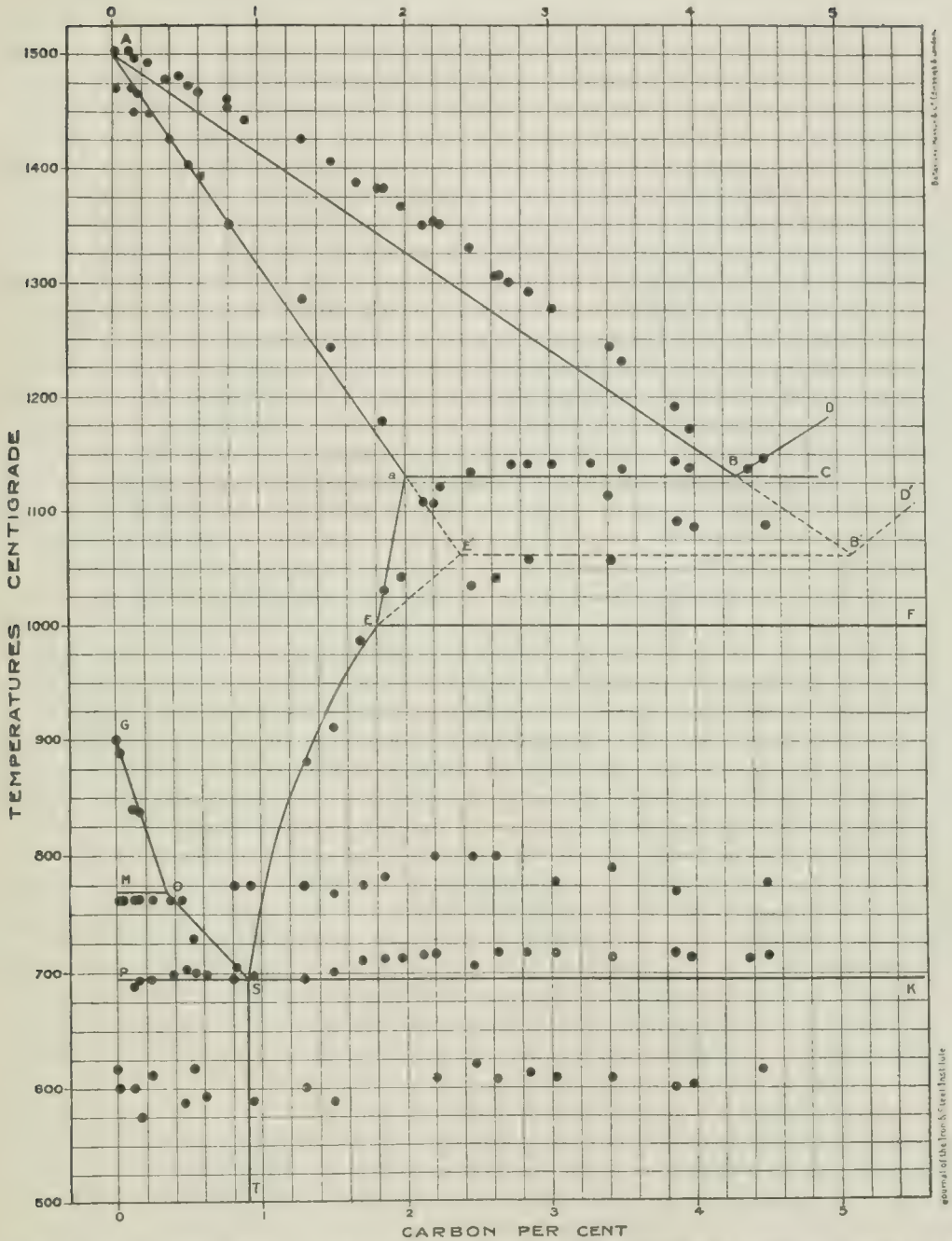


Fig. 11. — The Iron-Carbon Diagram of Roozeboom-Roberts-Austen (after Carpenter and Keeling). The black dots show Carpenter and Keeling's results. Reproduced from the "Iron and Steel Magazine," Vol. VII, 1904, page 640. See also the "Journal of the Iron and Steel Institute," May, 1904.

From this diagram we may find for any percentage of carbon the temperatures at which occur the critical points on cooling. The latter are known as Ar_3, Ar_2, and Ar_1, respectively, in low carbon alloys; Ar_{3-2} and Ar_1 in medium carbon alloys, and Ar_{3-2-1} in high carbon alloys.

Table 5.

Comparison of Thermometric Scales, for every 10° C. and every 25° F.

C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.	C.	F.
—17.8	0.0	260	500	550	1022	774	1425	1000	1832	1290	2354	1580	2875
0.0	32	270	518	552	1025	779	1434			1300	2372	1580	2876
10.0	50	274	525	560	1040	780	1436	1010	1850			1590	2894
20.0	68	280	536	566	1050	788	1450	1020	1868	1302	2375	1593	2900
23.9	75	288	550	570	1058	790	1454	1024	1875	1310	2390	1600	2912
30.0	86	290	554	580	1075	794	1461	1030	1886	1316	2400		
37.8	100	300	572	580	1076	800	1472	1038	1900	1320	2408	1625	2957
40.0	104			590	1094			1040	1904	1329	2425	1650	3002
50.0	122	302	575	593	1100	802	1475	1050	1922	1330	2426	1675	3047
51.7	125	310	590	600	1112	808	1486	1052	1925	1340	2444	1700	3092
60.0	140	316	600			810	1490	1060	1940	1343	2450	1750	3182
65.6	150	320	608	607	1125	816	1500	1066	1950	1350	2462	1800	3272
70.0	158	330	625	610	1130	820	1508	1070	1958	1357	2475	1850	3362
79.4	175	330	626	620	1148	830	1525	1080	1975	1360	2480	1900	3452
80.0	176	340	644	621	1150	830	1526	1080	1976	1370	2498	1950	3542
90.0	194	343	650	630	1166	840	1544	1090	1994	1371	2500	2000	3632
93.3	200	350	662	635	1175	843	1550	1093	2000	1380	2516	2050	3722
100	212	357	675	640	1184	850	1562	1100	2012	1385	2525	2100	3812
		360	680	649	1200	851	1564			1390	2534		
107	225	370	698	650	1202	857	1575	1107	2025	1399	2550		
110	230	371	700	657	1215	860	1580	1110	2030	1400	2552		
120	248	380	716	660	1220	866	1591	1120	2048				
121	250	385	725	663	1225	870	1598	1121	2050	1410	2570		
130	266	390	734	664	1227	871	1600	1130	2066	1413	2575		
135	275	399	750	670	1238	880	1616	1135	2075	1420	2588		
140	284	400	752	677	1250	882	1620	1140	2084	1427	2600		
149	300			678	1252	885	1625	1149	2100	1430	2606		
150	302	410	770	680	1256	890	1634	1150	2102	1440	2624		
160	320	413	775	690	1274	897	1647	1160	2120	1441	2625		
163	325	420	788	691	1275	899	1650	1163	2125	1450	2642		
170	338	427	800	693	1280	900	1652	1170	2138	1455	2650		
177	350	430	806	700	1292			1177	2150	1460	2660		
180	356	440	824			910	1670	1180	2156	1469	2675		
190	374	441	825	705	1300	913	1675	1190	2174	1470	2678		
191	375	450	842	707	1304	920	1688	1191	2175	1480	2696		
200	392	455	850	709	1308	927	1700	1200	2192	1482	2700		
		460	860	710	1310	930	1706			1490	2714		
204	400	469	875	714	1317	940	1724	1205	2200	1496	2725		
210	410	470	878	719	1325	941	1725	1210	2210	1500	2732		
218	425	480	896	720	1328	950	1742	1219	2225				
220	428	482	900	722	1332	952	1746	1220	2228	1510	2750		
230	446	490	914	726	1338	955	1750	1230	2246	1520	2768		
232	450	496	925	730	1346	960	1760	1232	2250	1524	2775		
240	464	500	932	732	1350	969	1775	1240	2264	1530	2786		
246	475			736	1357	970	1778	1246	2275	1538	2800		
250	482	510	950	737	1359	973	1783	1250	2282	1540	2804		
		520	968	740	1364	980	1796	1260	2300	1550	2822		
		524	975	746	1375	982	1800	1270	2318	1552	2825		
		530	986	750	1382	984	1803	1274	2325	1560	2840		
		538	1000	756	1393	990	1814	1280	2336	1566	2850		
		540	1004	760	1400	996	1825	1288	2350	1570	2858		
				770	1418								

C.	F.
1° =	1.8°
2° =	3.6°
3° =	5.4°
4° =	7.2°
5° =	9.0°
6° =	10.8°
7° =	12.6°
8° =	14.4°
9° =	16.2°

Formulæ for converting from one scale into the other:

$$F = \frac{9C}{5} + 32;$$

$$C = \frac{5\,(F-32)}{9}$$

F = degrees Fahrenheit.

C = degrees Centigrade.

With the exception of the first column, which has been calculated, this table has been taken from Howe's " Metallurgical Laboratory Notes," page 127, by permission of the author.

Experiment 16.

Data for Heating and Cooling Curves of High Carbon Steel.

HEATING.			COOLING.		
Temperature Deg. C.	Time.	Difference.	Temperature Deg. C.	Time.	Difference.
500			900		
510			890		
520			880		
530			870		
540			860		
550			850		
560			840		
570			830		
580			820		
590			810		
600			800		
610			790		
620			780		
630			770		
640			760		
650			750		
660			740		
670			730		
680			720		
690			710		
700			700		
710			690		
720			680		
730			670		
740			660		
750			650		
760			640		
770			630		
780			620		
790			610		
800			600		
810			590		
820			580		
830			570		
840			560		
850			550		
860			540		
870			530		
880			520		
890			510		
900			500		

Experiment 16.

Data for Heating and Cooling Curves of Medium Carbon Steel.

HEATING.			COOLING.		
Temperature Deg. C.	Time.	Difference.	Temperature Deg. C.	Time.	Difference.
500			900		
510			890		
520			880		
530			870		
540			860		
550			850		
560			840		
570			830		
580			820		
590			810		
600			800		
610			790		
620			780		
630			770		
640			760		
650			750		
660			740		
670			730		
680			720		
690			710		
700			700		
710			690		
720			680		
730			670		
740			660		
750			650		
760			640		
770			630		
780			620		
790			610		
800			600		
810			590		
820			580		
830			570		
840			560		
850			550		
860			540		
870			530		
880			520		
890			510		
900			500		

Experiment 16.

Data for Heating and Cooling Curves of High Carbon Steel.

HEATING.			COOLING.		
Temperature Deg. F.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.
900			1650		
925			1625		
950			1600		
975			1575		
1000			1550		
1025			1525		
1050			1500		
1075			1475		
1100			1450		
1125			1425		
1150			1400		
1175			1375		
1200			1350		
1225			1325		
1250			1300		
1275			1275		
1300			1250		
1325			1225		
1350			1200		
1375			1175		
1400			1150		
1425			1125		
1450			1100		
1475			1075		
1500			1050		
1525			1025		
1550			1000		
1575			975		
1600			950		
1625			925		
1650			900		

Experiment 16.

Data for Heating and Cooling Curves of Medium Carbon Steel.

HEATING.			COOLING.		
Temperature Deg. F.	Time.	Difference.	Temperature Deg. F.	Time.	Difference.
900			1650		
925			1625		
950			1600		
975			1575		
1000			1550		
1025			1525		
1050			1500		
1075			1475		
1100			1450		
1125			1425		
1150			1400		
1175			1375		
1200			1350		
1225			1325		
1250			1300		
1275			1275		
1300			1250		
1325			1225		
1350			1200		
1375			1175		
1400			1150		
1425			1125		
1450			1100		
1475			1075		
1500			1050		
1525			1025		
1550			1000		
1575			975		
1600			950		
1625			925		
1650			900		

Experiment 17.

TO ILLUSTRATE THE CHANGES IN MAGNETIC PROPERTIES OCCURRING AT THE THERMAL CRITICAL POINTS IN STEEL.

Steel at a high temperature is non-magnetic. — A small piece of steel should be heated in the blast lamp to a white heat and held in the vicinity of an electromagnet. It will be found that the steel is not attracted by the magnet.

Steel regains its magnetic properties on cooling. — As the piece cools, it is again attracted by the magnet.

Description of apparatus.[1] — The apparatus consists essentially of three parts, namely, an electromagnet, *A*, Fig. 12; a support, *B*, for the test piece, and a Le Chatelier thermo-electric couple, *C*. An adjustable wrought-iron core, *d*, is suspended inside the magnet coil. Asbestos gaskets, *ww*, protect the coil from the heat of the blast lamps used for heating the test-piece. The hot-junction, *h*, of the thermo-couple is placed inside the drilled test-piece, *s*, as indicated in the illustration. A bottle, *j*, holds cold distilled water in which is immersed the cold-junction of the thermo-couple. The temperature of the water and, therefore, of the cold-junction may be ascertained at any moment by means of a thermometer suspended in the water. The apparent temperature of the steel test-piece may be read at any moment on the galvanometer, *g*. To this apparent temperature must be added the temperature of the cold junction (see text and footnote on page 13 of this book).

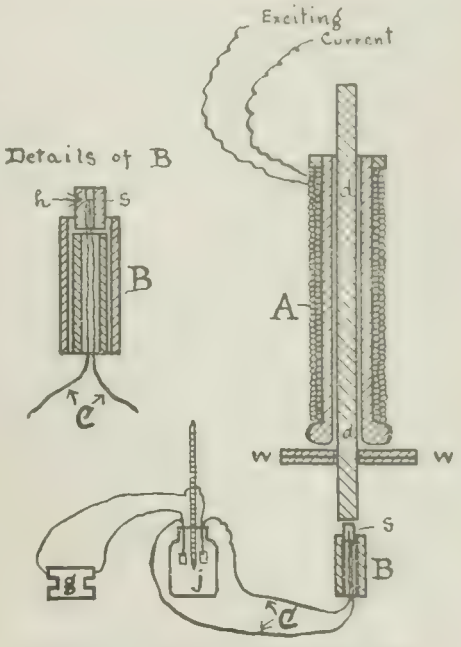


Fig. 12. — Apparatus for Illustrating Changes in Magnetic Properties.

Procedure. — A piece of $\frac{1}{2}$-inch round steel[2] about $\frac{3}{4}$ inch long and containing about 1.00 per cent of carbon is carefully drilled longitudinally through its center with a $\frac{1}{8}$-inch drill, and the ends of this test-piece are ground flat, normal to its length.[3]

The drilled test-piece is now placed over the hot junction of the thermo-couple (see Fig. 12), resting upon the inner tube of the porcelain support so that the upper end of the steel

[1] A more detailed description of this apparatus may be found in an article by one of the authors in the "Electrochemical and Metallurgical Industry," Vol. VI, 1908, pages 273 and 321.

[2] The piece of steel used in Experiment 10 should be used if possible. If this is not convenient, then use a piece with the same carbon content and preferably from the same bar as the piece used in the previous experiment (16).

[3] The experiment is best carried out with high carbon steels containing more than 0.80 per cent of carbon, as such steels have only one critical point, Ac_{3-2}, on heating, or Ar_{3-2} on cooling (see Fig. 11), and that point is very marked, but the figures given in Table 1, in the article referred to above in the first footnote, show that steels with less carbon give good results, remembering that the critical points determined by this method would be Ac_{3-2} and Ar_{3-2} in medium carbon steels and Ac_2 and Ar_2 in low carbon steels.

remains not more than ½ inch below the lower end of the unmagnetized core. The hot junction of the thermo-couple is now inside the steel piece and a little below the top surface of that piece. The upper end of the outer porcelain tube acts as a protecting collar to the portion of the thermo-couple necessarily bared when the test piece is lifted later by the magnet.

The exciting current of the electromagnet is now turned on and remains on during the entire experiment.

The loss of magnetism on heating occurs at the critical range. — The test piece, which is now clinging to the magnet, is heated gently and gradually by means of two blast lamps,[1] one on each side, and the temperature at which the piece ceases to be attracted is carefully noted.[2] It should be found to agree closely to the thermal critical point Ac_{2-1} of the steel as determined in Experiment 10. This correspondence may be automatically checked by noting that very nearly at the instant the test piece drops, the galvanometer needle will stop short, or even reverse its direction of motion slightly, indicating that the well known absorption of heat or retardation of heating is taking place.

The recovery of magnetism on cooling occurs at the critical range. — The heating should be continued until the piece is at white heat, when the lamps should be withdrawn, allowing the piece to cool in the close vicinity (within ½ inch) of the magnet. The temperature at which the piece is again attracted should be carefully noted.[2] It should be found to correspond closely to the critical point Ar_{3-2-1} as determined in Experiment 16.

Experiment repeated. — The experiment should be repeated several times and the average of the corrected temperatures determined. These averages should be compared with the results obtained in Experiment 10, the latter results being recorded in the proper place in the laboratory report for this experiment. The averages of many results obtained in this laboratory are shown in Table 9. In both cases the steel contained about 1.00 per cent of carbon.

TABLE 9. — RESULTS OBTAINED BY STUDENTS AT HARVARD UNIVERSITY.

Steel Number.	Method.	Ac_{3-2-1}	Number of Tests.	Ar_{3-2-1}	Number of Tests	Date.
1	Magnetic.....	753	72	679	75	1906
	Ordinary.....	739	14	688	12	
2	Magnetic	752	131	695	130	1907
	Ordinary	750	13	695	17	

[1] The fact that the lower ½ inch of the test-piece is not heated as rapidly as the rest of the piece because of the porcelain collar surrounding it does not interfere with the measurement of the temperature at which the piece loses its magnetic properties, for the hot junction is situated near the top of the ¾-inch-long test-piece.

[2] At the same time that this temperature is noted the temperature of the cold junction should also be noted and recorded.

Experiment 17.

LABORATORY REPORT.

The Thermal Critical Points of Steel as Determined by Noting the Temperatures at which the Loss and the Recovery of its Magnetic Properties Occur.

Carbon content of steel = .

	TEMPERATURE AT WHICH MAGNETIC PROPERTIES ARE LOST.			TEMPERATURE AT WHICH MAGNETIC PROPERTIES ARE RECOVERED.		
	Apparent Temperature. Deg.	Correction for Cold Junction.	Corrected Temperature. Deg.	Apparent Temperature. Deg.	Correction for Cold Junction.	Corrected Temperature. Deg.
1st Reading						
2d Reading						
3d Reading						
4th Reading						
5th Reading						
		Total			Total	
	Mean critical point (corrected).	Deg. F.		Mean critical point (corrected).	Deg. F.	
		Deg. C.			Deg. C.	
	Temperature of retardation as determined in previous experiment (corrected).			Temperature of retardation as determined in previous experiment (corrected).		

Remarks : *Date :*

Experiment 18.

TO ILLUSTRATE THE RELATION BETWEEN THE CRITICAL POINTS AND THE HARDENING POWER OF STEEL; ALSO THE BRITTLENESS PRODUCED BY HARDENING.

Each student will cut five pieces of steel wire 3 inches long and containing 0.50 to 0.75 per cent of carbon. They should be marked respectively 1, 2, 3, 4, and 5.

No. 1 should be heated to a white heat by means of a blast lamp and quickly dropped into cold water. This wire evidently will have been quenched at a temperature greatly exceeding the critical point of the steel.

No. 2 should be heated to a white heat and held near the magnet and quenched after it has recovered its magnetism. This wire will have been quenched soon after it has passed through its critical points on cooling.

No. 3 should be supported by the magnet and carefully heated until, losing its magnetism, it will fall by its own weight into the cold water. This sample will have been quenched as soon as it has passed through its critical points on heating.

No. 4 should be heated until barely red and quenched in water. This sample will have been quenched considerably below its critical points.

No. 5 should be left untreated.

Each wire will now be bent gradually in the middle until bent flat or until fracture occurs.

It should be found that wires 2, 4, and 5 can be bent flat, while 1 and 3 break after slight bending; they are brittle.

The fragments of the broken wires as well as the unbroken wires should be attached to a piece of cardboard with gummed paper. Write in this book and on the card briefly your own conclusions: (1) As to the relation between the hardening power of steel and its thermal critical points; and (2) as to the brittleness resulting from hardening.

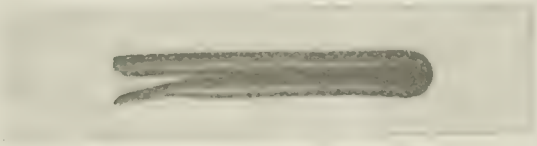
Fig. 13 shows the results of bending these wires after the respective heat treatments.

(See p. xx at page.)

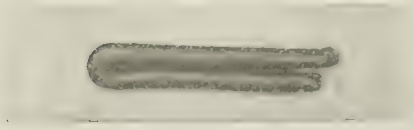
No. 1. Quenched at white heat; hard and very brittle.

No. 2. Quenched just below the critical points on cooling; tough.

No 3. Quenched justa bove the critical points on heating; hard, but not so brittle as No. 1.



No. 4. Quenched at dull red heat; tough.



No. 5. Untreated; tough.

Fig. 13. — Result of Quenching Steel Wires (containing about 0.70% Carbon) at Different Temperatures. (Reproduced full size.)

Experiment 19.

TO ILLUSTRATE THE RELATION BETWEEN THE CRITICAL POINTS AND THE HARDENING POWER OF STEEL; ALSO THE HARDNESS PRODUCED IN HIGH-CARBON STEEL BY SUDDEN COOLING (QUENCHING) FROM A HIGH TEMPERATURE.

Each squad will cut five pieces ½ inch long from a steel bar containing about 1.00 per cent carbon. These pieces should be marked respectively 1, 2, 3, 4, and 5.

No. 1 should be heated to a white heat that is well above the critical point of the steel, and quickly dropped into cold water.

No. 2 should be heated to a bright red heat and quenched shortly after it has recovered its magnetism by shutting off the current supplying the electro-magnet and allowing the piece to fall into the water. We have quenched this piece soon after the critical transformation was completed on cooling.

No. 3, properly supported by a magnet should be heated until it ceases to be magnetic, falling by its own weight into a pail of water. In this way we have evidently quenched this piece as soon as the critical transformation was completed on heating.

No. 4 should be heated to a dull red heat and quenched.

No. 5 should be left untreated.

Each piece should now be tested on one edge with a file. It will be found that Nos. 2, 4, and 5 can be filed quite readily, while 1 and 3 are too hard to be filed.

Brinell's test for hardness. Each piece should be placed in the testing machine and a hardened steel ball pressed into it under a load of 3,000 pounds. In this way an impression will be made in each piece, which will be the deeper the softer the steel.

Adapter for Brinell Ball Test. — An adapter devised by the authors for using an Olsen transverse testing machine in the Brinell ball test for hardness is shown in Fig. 14. It consists of two parts, a bar, *A*, of large cross section to insure stiffness, and a block, *B*, both made of tool steel. The block, *B*, has in the center of the bottom a spherical depression made by a hardened steel ball such as is used in the ball test, under a pressure considerably greater than that used in the test itself. In the particular machine for which this adapter was devised, the power is applied by hand-wheel and screw through *C*; *D* is the stationary fulcrum and *E* is the bearing connected to the compound lever on which are hung the compensating weights.

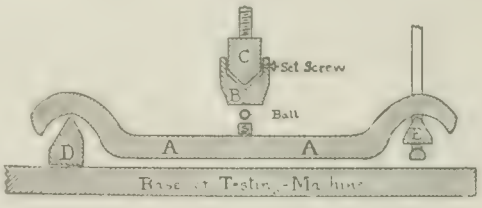
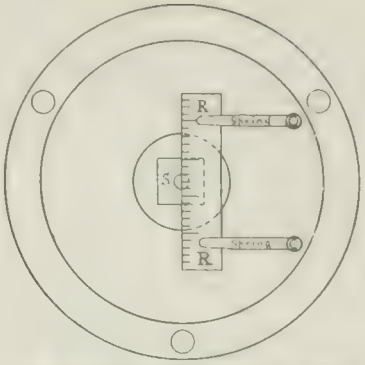


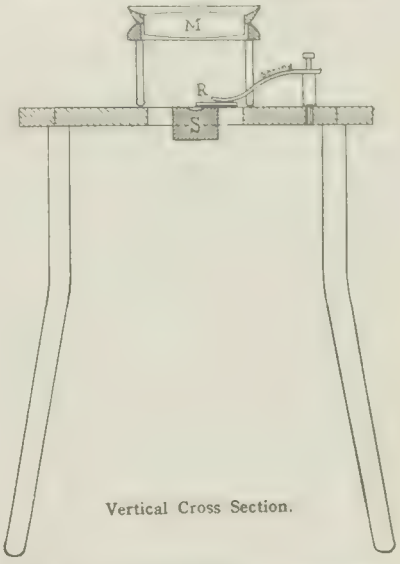
Fig. 14. — Adapter for making Brinell Ball Test.

The diameter of the spherical impression thus produced should be carefully measured with a pair of calipers, or by the device shown in Fig. 15, and the corresponding surface, *s* of the impression and a factor of hardness, *H*, will be found in Table 10.

Device for measuring diameters of impressions made in Brinell Ball Test. — This was designed by the authors and is shown in Fig. 15. An ordinary iron tripod is fitted with an iron or wooden cover, in the center of which is a hole about ¾ inch in diameter. A very thin steel scale, *RR*, graduated in tenths of a millimeter or hundredths of an inch, is held tight over this hole by means of spring-clips. The piece of steel to be measured, *S*, is held by hand underneath the scale so that the edge of the scale corresponds to a diameter of the impression to be measured. *M* is a small tripod magnifier by which the diameter of the impression is more easily read. The upper portion of the sketch shows a plan view of the tripod-top without the magnifier.



Plan View of Tripod-top without Magnifier.



Vertical Cross Section.

Fig. 15. — Device for Measuring Diameters of Impressions.

It should be found that the impressions produced in Nos. 2, 4, and 5 are practically of the same size, which means that their hardness is the same. Pieces 1 and 3 should be found to have the same hardness, but to be much harder than the former three samples.

Conclusions. — This experiment teaches that steel acquires its hardening power during the retardation on heating and loses it at the critical point on cooling. To harden steel, therefore, it is necessary and sufficient to heat the metal past its critical point and then to cool it suddenly. It also shows that little, if any, increase of hardness results from heating it to a temperature much above the critical temperature, since samples 1 and 3 exhibit the same or nearly the same degree of hardness. The student should write these conclusions briefly in the proper part of the laboratory report.

TABLE 10.[1]—HARDNESS FACTORS FOR BRINELL BALL TEST

D. Mm.	S. Mm²	H. $\frac{5000}{S}$	H. $\frac{3000}{S}$	D. Mm.	S. Mm².	H. $\frac{5000}{S}$	H. $\frac{3000}{S}$	D. Mm.	S. Mm².	H. $\frac{5000}{S}$	H. $\frac{3000}{S}$
1.50	1.8095	2,770	1,660	3.55	10.2353	488	293	5.60	26.9392	186	112
1.55	1.8975	2,640	1,582	3.60	10.5338	476	286	5.65	27.1733	182	109
1.60	2.0232	2,480	1,487	3.65	10.8416	462	277	5.70	28.0168	178	107
1.65	2.1866	2,290	1,373	3.70	11.1495	448	269	5.75	28.5634	175	105
1.70	2.2871	2,180	1,310	3.75	11.4495	436	262	5.80	29.1163	172	103
1.75	2.4378	2,055	1,236	3.80	11.7496	425	255	5.85	29.6818	169	101
1.80	2.5761	1,940	1,164	3.85	12.0951	414	248	5.90	30.2530	166	99
1.85	2.7112	1,848	1,108	3.90	12.4407	402	241	5.95	30.8316	162	97
1.90	2.8620	1,750	1,048	3.95	12.7785	392	235	6.00	31.4160	159	95
1.95	3.0159	1,660	995	4.00	13.1162	382	228	6.05	32.0066	156	94
2.00	3.1762	1,577	946	4.05	13.4712	372	223	6.10	32.6098	153	92
2.05	3.3427	1,498	898	4.10	13.8262	362	217	6.15	33.2130	151	90
2.10	3.5029	1,430	857	4.15	14.1749	353	212	6.20	33.8350	148	89
2.15	3.6757	1,361	817	4.20	14.5236	345	207	6.25	34.4602	145	87
2.20	3.8485	1,304	782	4.25	14.8943	336	202	6.30	35.0634	143	86
2.25	4.0275	1,242	744	4.30	15.2650	326	196	6.35	35.7325	140	84
2.30	4.2097	1,189	713	4.35	15.6451	319	192	6.40	36.3828	138	82
2.35	4.3982	1,139	683	4.40	16.0253	312	187	6.45	37.0426	135	81
2.40	4.5930	1,090	652	4.45	16.4148	304	183	6.50	37.7080	133	80
2.45	4.7885	1,045	627	4.50	16.8044	297	179	6.55	38.3872	131	79
2.50	4.9889	1,000	600	4.55	17.2065	291	174	6.60	39.0720	128	77
2.55	5.1931	963	578	4.60	17.6087	284	170	6.65	39.7632	126	76
2.60	5.4036	925	555	4.65	18.0186	278	166	6.70	40.4700	124	74
2.65	5.6188	889	532	4.70	18.4286	272	163	6.75	41.1832	122	73
2.70	5.8340	855	512	4.75	18.8527	265	159	6.80	41.9058	119	71.5
2.75	6.0586	827	495	4.80	19.2768	259	156	6.85	42.6409	117	70
2.80	6.2832	798	477	4.85	19.7135	254	153	6.90	43.3855	115	69
2.85	6.5172	767	460	4.90	20.1502	249	149	6.95	44.1394	113	68
2.90	6.7513	741	444	4.95	20.5978	244	146	7.00	44.9028	111	67
2.95	6.9696	718	430	5.00	21.0455	238	143				
3.00	7.1880	696	418	5.05	21.5042	233	140				
3.05	7.4629	670	402	5.10	21.9629	228	137				
3.10	7.7378	645	387	5.15	22.4357	223	134				
3.15	8.0001	625	375	5.20	22.9085	218	131				
3.20	8.2624	606	364	5.25	23.3939	215	128				
3.25	8.5310	587	351	5.30	23.8793	210	126				
3.30	8.7996	569	340	5.35	24.3694	206	124				
3.35	9.0792	551	332	5.40	24.8720	201	121				
3.40	9.3588	535	321	5.45	25.3778	197	118				
3.45	9.6478	518	311	5.50	25.8931	193	116				
3.50	9.9369	502	302	5.55	26.4114	190	114				

D = diameter of impression.

S = surface of spherical impression.

H = factor of hardness = load divided by surface of impression.

[1] The figures in this table are taken from a larger table in "*Hållfasthetsprofvning medelst stål-kulans intryckning*," by J. A. Brinell, 1901, pages 16 to 18, and the ball used should have a diameter of 10 mm. If factors comparable with Brinell's results are desired, the load should be taken in kilograms. With the load in pounds, however, comparative hardness factors are obtained which are just as valuable for ordinary work.

Experiment 19.

LABORATORY REPORT.

The Hardness of 1% Carbon Steel after Various Treatments, as determined by the Brinell Ball Test.

No.	Treatment.	File Test.	Diam. of Impression.		Surface of Impression. S.	Load.	Hardness. $H = \frac{\text{Load}}{S}$.	REMARKS.
			Inches.	Mm.				
1	Quenched at white heat.							
2	Quenched after the critical transformation was completed on cooling.							
3	Quenched after the critical transformation was completed on heating.							
4	Quenched from dull red heat.							
5	Untreated.							

Conclusions :

Date :

Experiment 20.

TO ILLUSTRATE THE INFLUENCE OF HARDENING UPON THE DUCTILITY, ELASTICITY, AND TRANSVERSE STRENGTH OF STEEL.

From stock bars of ½-inch square steel, containing respectively 0.10, 0.50, and 1.00 per cent C., each squad will cut two bars of each steel, about 9 inches long.

One bar from each steel should be heated to about 850° C. and quenched in an abundant supply of cold water.

All bars should now be subjected to a transverse test, being placed on supports six inches apart and their elasticity, transverse strength, and deflection [1] ascertained.

Plot your results in the usual way and paste the result in this book opposite the laboratory report.

Draw your own conclusions as to the influence of hardening upon the ductility, elasticity, and transverse strength of steel, taking into consideration the percentage of carbon present, and write the conclusions on the sheet with the plotted results.

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[1] In this laboratory the deflection is measured by means of an index attached to the movable jaw of the Riehlé testing machine. The index moves along a fixed scale graduated to hundredths of an inch, and attached to the standard supporting the fixed jaw of the machine. Two readings are taken, one just as the upper bearing first touches the test-bar, the other at the position where the test-bar is fractured or when the limit of the machine has been reached. The difference between the two readings gives the deflection in hundredths of an inch.

Experiment 20.

LABORATORY REPORT.

Influence of Hardening upon the Ductility, Elasticity, and Transverse Strength of Steel.

Material Tested	Carbon Content.	Marked.	Dimension of Test Piece		Area of Section in Sq. In.	Elastic Limit in Lbs	Maximum Load in Lbs.	Distance between Rests	ELASTIC LIMIT per Sq. In. in Lbs.	TRANSVERSE STRENGTH per Sq. In. in Lbs	Deflection Readings.	Deflection in Inches.	REMARKS.
			Length	Cross Section.									

Experiment 21.

TO ILLUSTRATE THE INFLUENCE OF CARBON UPON (1) THE HARDNESS AND (2) THE HARDENING POWER OF STEEL.

Each squad should cut from stock bars, containing respectively 0.10, 0.30, 0.50, 0.80, and 1.25 per cent carbon, two pieces about $\frac{3}{8}$ inch in length.[1]

One piece from each bar should be subjected to the Brinell test in order to ascertain the hardness of the metal before treatment.

The other samples (one from each bar) should be heated to about 850° C., quenched in water, and their hardness ascertained by the same test.

The results should be tabulated in the laboratory report and should also be plotted, with carbon content as abscissæ and hardness numbers as ordinates. The plotted results should be pasted in this book under the laboratory report.

Draw your own conclusions regarding (1) the influence of carbon upon the hardness of steel; (2) the influence of carbon upon the hardening power of steel, and write them on the blank page opposite the laboratory report.

[1] The pieces should be of as nearly the same size as possible.

Experiment 21.

LABORATORY REPORT.

The Influence of Carbon Content upon the Hardening Power of Steel, as Determined by the Brinell Ball Test.

Carbon Content.	Marked.	BEFORE TREATMENT. Diameter of Impression. Inches.	Mm.	Factor of Hardness. H_1	AFTER TREATMENT. Diameter of Impression. Inches.	Mm.	Factor of Hardness. H_2	Increase in Hardness due to Quenching. $H_2 - H_1$	REMARKS.

Paste the plotted curve below :

Date :

Experiment 22.

TO ILLUSTRATE THE INFLUENCE OF THE NATURE OF THE QUENCHING BATH UPON THE HARDENING OF STEEL.

From stock bars containing about 0.30 per cent carbon, *each student* will cut four pieces about $\frac{3}{8}$ inch in length.[1]

Grind all the pieces so that the two faces are smooth and parallel.

One piece should be subjected to the ball test in order to ascertain the hardness of the metal before treatment.

The other three pieces should be heated to 850° C. and quenched respectively in oil, cold water, and iced brine.

The hardness of these quenched samples should be determined by the ball test.

The results should be tabulated in the laboratory report and should also be plotted with quenching baths as abscissæ and factors representing the increase of hardness as ordinates.

Note that the rate of cooling is most rapid with iced brine and least rapid with oil.

Draw your own conclusions regarding the influence of the nature of the quenching bath upon the hardening of steel and write the conclusions you have formed upon the blank page opposite the laboratory report.

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[1] The pieces should be of as nearly the same size as possible.

Experiment 22.

LABORATORY REPORT.

To Illustrate the Influence of the Nature of the Quenching Bath upon the Hardening of Steel.

Carbon Content = ...

Marked.	Treatment.	Diam. of Impression.		Factor of Hardness.	[illegible]	REMARKS.
		Inches.	Mm.			
U	Untreated.					
	Quenched at [illegible] C. in					
O	Oil.					
W	Cold Water.					
B	Iced Brine.					

Paste the plotted curve below :

Date :

Experiment 23.

THE TEMPERING OF HARDENED STEEL.

Each squad of *two students* will cut from stock bars containing about 0.50 per cent carbon six pieces about ⅝ inch in length.[1]

Grind all samples so that the two faces are smooth and parallel.

Mark the samples respectively, U, O, 2, 3, 4, and 8.

Set one (marked U) aside to be tested without previous treatment. The other five samples should be placed in the furnace, inside a covered scorifer to prevent undue oxidation, heated to about 850° C., and quenched in cold water.

The hardness of one of the samples (marked O) should be ascertained by the ball test.

One end of each of the other four hardened samples should be brightened by very gentle rubbing on the emery wheel, or better, by hand on emery cloth.[2] They should then be placed in a muffle furnace (preferably an electric muffle) and carefully heated to 225° C., when one of them (marked 2) should be taken out and allowed to cool. A second piece (marked 3) should be taken out when the pyrometer registers a temperature of 300°, a third one (marked 4) at 400°, and the last (marked 8) at 800°.

These four hardened and tempered samples should now be subjected to the ball test in order to ascertain their hardness.

All results should be tabulated and plotted in the usual way.

A bright piece of wire should be heated by each student to 800° C., and quenched in water. Holding the piece by one end, the other end should now be heated gently so as to develop the tempering colors, which should be carefully noted. These tints, which vary from a light yellow to a deep blue, indicate the amount of tempering done, and it is upon their appearance that the blacksmith generally depends for the successful tempering of his steel

[1] The pieces should be of as nearly the same size as possible.

[2] Great care should be observed in polishing these hardened specimens lest the heat developed by friction should prematurely temper the steel.

Experiment 23.

LABORATORY REPORT.

The Tempering of Hardened Steel.

Carbon Content = _____

Marked.	Treatment	Depth of Impression		Factor of Hardness.	Color of Specimen	REMARKS
		Inches.	Mm			
U	Untreated.					
	Quenched in cold water at 850° C. and reheated to					
0	Not reheated.					
2	225° C. and cooled					
3	300° C. „ „					
4	400° C. „ „					
8	800° C. „ „					

Paste the plotted results below :

Date :

Experiment 24.

TO ILLUSTRATE THE INFLUENCE OF CERTAIN HEAT TREATMENTS UPON THE PROPERTIES OF STEEL.

This experiment should be conducted by squads of three students.

Cut five bars of steel containing about 0.50 per cent carbon and measuring 12 inches in length.

Mark them 1, 2, 3, 4, and 5.

Bar 1 should be subjected to a tensile test in the usual way.

Bars 2 and 3 should be heated to 1000° C., when bar 2 should be removed from the furnace and allowed to cool in the air, while bar 3 should be cooled with the furnace.

Bars 4 and 5 should be heated in another furnace to 825° C., when bar 4 should be removed and cooled in air, while bar 5 cools with the furnace.

Bars 2, 3, 4, and 5 should now be subjected to a tensile test.

The results from the tensile tests should be reported (1) in the usual way and (2) by plotting the tenacity curve, the elastic limit curve, and the elongation curve in the usual way.

Draw your own conclusions from these experiments and write them on the sheet bearing the plotted curves. The sheet should then be pasted in this book on the blank page opposite the laboratory report.

Experiment 24.

LABORATORY REPORT.

To Illustrate the Influence of Certain Heat Treatments upon the Physical Properties of Steel.

Material Tested.	Marked.	Dimension of Test Piece. Length.	Cross Section.	Area of Section in Sq. In.	Elastic Limit in Lbs.	Maximum Load in Lbs	Elongation in In.	Reduced Cross Section.	Area of Reduced Section in Sq. In.	**ELASTIC LIMIT** per Sq. In. in Lbs.	**TENSILE STRENGTH** per Sq. In. in Lbs.	**ELONGATION** Per Cent of Gauged Length.	**REDUCTION** of Sectional Area Per Cent	REMARKS.

Experiment 25.

TO ILLUSTRATE THE EFFECT OF ANNEALING UPON THE PROPERTIES OF COLD WORKED STEEL.

Each squad will cut three pieces, about 10 inches in length, of some cold worked wire.

Two pieces should be heated in a furnace and one of them taken out and cooled slowly in the air, when the pyrometer indicates a temperature of 550° C., which is lower than the critical point; while the other should be heated to 800° C., cooling slowly in the furnace to 600° C., and then in the air to atmospheric temperature. The latter piece will have been properly annealed.

The three pieces of wire should now be tested in the testing-machine and special attention should be given to their elastic limit.

The results of these tests should be tabulated and plotted in the usual way and pasted in this book on the blank page opposite the laboratory report.

Draw your own conclusions regarding the effect of reheating cold worked steel, taking into consideration the annealing temperature and the strength, ductility, and elastic limit of the steel. Write these conclusions on the sheet bearing the plotted results.

Experiment 25.

LABORATORY REPORT.

To Illustrate the Effect of Annealing upon the Properties of Cold Worked Steel.

Material Tested.	Marked.	Dimension of Test Piece.		Area of Section in Sq. In.	Elastic Limit in Lbs.	Maximum Load in Lbs.	Elongation in ..... In.	Reduced Cross Section.	Area of Reduced Section in Sq. In.	ELASTIC LIMIT per Sq. In. in Lbs	TENSILE STRENGTH per Sq. In. in Lbs.	ELONGATION Per Cent. of Gauged Length.	REDUCTION of Sectional Area Per Cent.	REMARKS.
		Length.	Cross Section.											

Experiment 26.

TO ILLUSTRATE THE EFFECT OF HEAT UPON THE GRAIN OF STEEL.

(A Modification of Metcalf's Experiment.)

Nicking. — Each squad of *two students* will cut a bar of steel 6 inches long from stock 2½ inches wide and ⅜ inch thick, containing about 1.00 per cent carbon. The bar will be heated to about 900° C., and while red hot placed upon the anvil and nicked on both sides, as shown in Fig. 16.

After the bar is black it should be plunged into water to hasten its cooling.

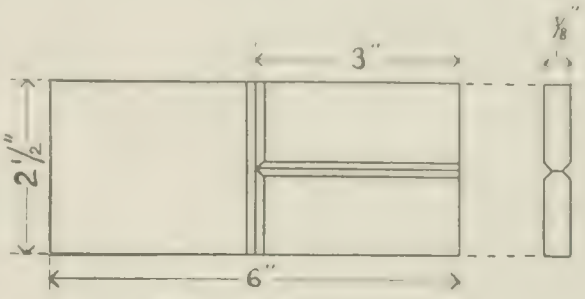

Fig. 16. — Method of Nicking Bars.

Procedure. — The nicked end of the bar should be inserted in a forge-fire and the operation so conducted as to heat the extremity (say 1 inch) to a scintillating white heat while the other end remains black. The temperature of the bar in this way will fall gradually from one end to the other.

As soon as the bar has been properly heated it should be quenched quickly in cold water *on a rising temperature* and carefully dried by holding it over the fire.

The nicked portions of the bar should now be broken up by sharp blows with a sledge-hammer and the exposed fracture carefully examined. It will be found that the extreme end of the fracture, corresponding to the highest temperature, is very coarse and that the fracture becomes finer as we approach the cool end, assuming finally a very fine grain. This is the place chosen as the point called *C* in Fig. 17. To the left of this portion the fracture becomes abruptly coarse and corresponds to that of the untreated steel, that is, to the fracture of the steel before it was reheated in the forge.

Conclusions. — This experiment teaches that by heating steel to a very high temperature its fracture or grain becomes very coarse and that its coarseness decreases with the temperature. It also teaches that to a certain temperature corresponds a very fine fracture, the finest fracture which the metal is capable of assuming. If the steel be heated below that temperature it retains its original fracture. The temperature which yields this very fine fracture is known to blacksmiths as the "refining heat." It corresponds to the critical point of the steel. In order to obtain this fine fracture the steel should be heated just past its critical point and immediately quenched.

Test for Hardness. — The hardness of this bar should be tested by the Brinell ball test at four points as indicated in Fig. 17.

The test at *A* will give the hardness of the untreated metal; that at *C*, the hardness at

Fig. 17. — Location of Ball Tests.

the refining heat; while at B and D it will indicate the hardness of the metal after quenching at temperatures respectively below and above the critical temperature. It should be found that the metal at B is not materially harder than at A, and that the metal at D is not materially harder than at C, which confirms the results on the influence of the critical point upon the hardening power of steel obtained in other experiments.

Experiment 26.

LABORATORY REPORT.

The Hardness of Steel containing about 1% Carbon when Quenched at Various Temperatures in Cold Water.

No.	Treatment	Diam. of Impression. Inches.	Diam. of Impression. Mm.	Factor of Hardness.	Appearance of Fracture.	REMARKS.
A	Quenched while cold.					
B	Quenched at just below the critical point.					
C	Quenched at the "refining heat."					
D	Quenched at scintillating white heat.					

Make a sketch of the fractured surface :

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